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BULLETIN

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American Association *of* Petroleum Geologists

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THE BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

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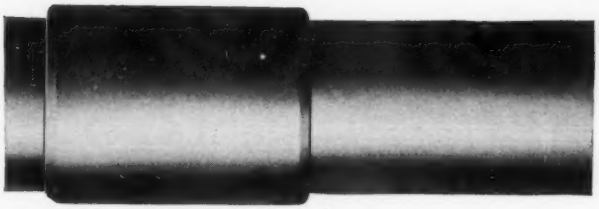

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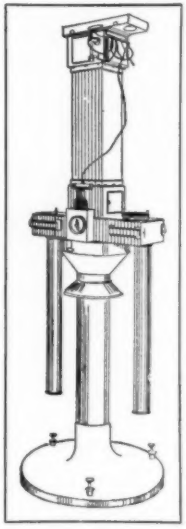

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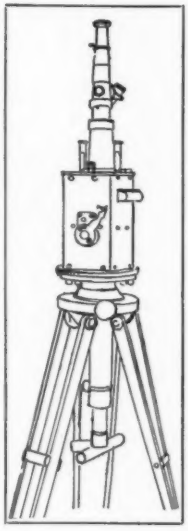

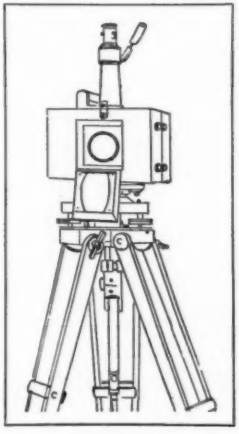

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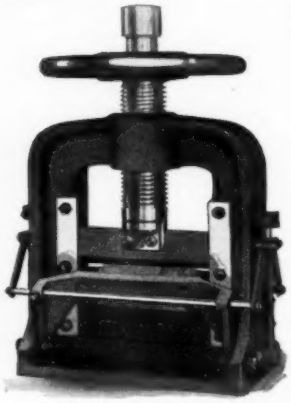

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NOVEMBER 1926

A BRIEF OUTLINE OF SOME OIL-ACCUMULATION PROBLEMS[1]

ALEX W. McCOY
Denver, Colorado

ABSTRACT

Problems of oil accumulation are divided, by this paper, into three main groups: first, origin of the material; second, transfer of oil from the source beds to the reservoir rock; third, the migration of petroleum in reservoir rocks. The paper discusses various possibilities under each of the foregoing headings. It points out the evidence which favors certain conclusions as well as the lack of evidence for some hypothetical assumptions. There are so many indefinite factors to these problems that no conclusions are presented.

INTRODUCTION

The purpose of this paper is to outline briefly some of the important problems in a study of oil accumulation, and to state a few facts of evidence which may question, or help demonstrate, the probabilities of certain conclusions. In doing so a liberal use of the published literature has been made and where possible references are cited for original ideas. In many cases, suggestions have been brought out through conversation, so that in order of acknowledgment, the writer can only express his indebtedness to all of his former and present co-workers in petroleum geology.

The importance of a correct and accurate interpretation of oil accumulation becomes paramount as the future search for new fields grows more difficult throughout the world. Unfortunately, an accurate solution of this problem borders on the impossible; consequently, our best efforts at the present time can only be exerted to bring forth the most probable conclusions.

[1] Presented before the Association at the Dallas Meeting, March, 1926.

A number of conflicting ideas have arisen from the literature, due largely to the fact that the different authors have been working on single phases of the problem, rather than analyzing the entire situation. These differences of opinion will doubtless harmonize eventually as a more critical application of scientific principles is made, and more of the improbable conclusions can be discarded as the science proceeds toward its proper goal.

The weight of geologic evidence so favorably substantiates the organic theory for the origin of oil that the discussion in this paper is based entirely upon this assumption.

The conditions of oil accumulation in so far as they interest the petroleum geologist, are divided into three outstanding groups:

First: The origin of bituminous material, and the stages through which this material has gone in becoming crude oil.

Second: The process by which the oil got into the sand or porous rock.

Third: The movement of the oil in the reservoir rock to account for commercial pools.

ORIGIN OF THE BITUMINOUS MATERIAL

The chemical actions by which animal and plant remains decay with first an elimination of albumin and cellulose, and later, an elimination of carbon dioxide and water from the fatty acids and esters, leaving hydrocarbons of high molecular weight containing oxy-compounds, have been well covered by Engler[1] and other writers. This residual material is most probably the basic source of crude petroleum, and waxlike hydrocarbons are found quite commonly in sedimentary rocks. Such sediments were evidently deposited in comparatively quiet, boggy basins of brackish or marine water. Attention has previously been called to the close relationship (that is, within a few hundred feet stratigraphically) of this type of sedimentation to the producing horizons of the majority of Mid-continent oil fields.[2] Takahashi[3] has described at some length the

[1] C. Engler, *Economic Geology*, Vol. 4, p. 625.

[2] A. W. McCoy, *Journal of Geology*, Vol. 27, p. 252.

[3] J. Takahashi, "Science Reports of Tohoki," *Imperial University, Series* 3, Vol. 1, p. 144.

relationship of "kerogen" shales to the oil fields of Japan. He briefly describes the lithological characters of the formation as follows:

> Our oil measure is composed of marine shales and sands mostly of a soft and friable nature, though towards the lower part hard and compact rocks, such as siliceous and marly shales, are found intercalated. The micro-fossils are relatively well preserved in the soft rocks while they are obscured in the hard shales.
>
> The lithological features of our oil-measures shales show a close resemblance in many respects to the Monterey shale of California.
>
> The shale cuts from the oil wells usually show the presence of kerogen even when the surface rocks fail to yield oil on distillation.
>
> The black shales from the regions where no economically important oil deposits are found, yield oil on distillation. Many of these shales are different in the fossil content and in the nature of the kerogen from the shales belonging to the oil measure.

Many other instances have been recorded indicating a relation of similar bituminous strata to producing horizons of oil fields throughout North America.

The rocks containing an appreciable amount of this bituminous material are characteristically fine-grained, usually tough, and originally absorb very little water. The waxy hydrocarbons seem to fill, more or less completely (according to relative percentages) the interstices of the rock structure.

It is generally agreed that sedimentary beds of this type are not the reservoirs of commercial oil pools although the weight of geologic evidence favors the conclusion that the source of petroleum was originally associated with such strata.

The first problem of consequence to the petroleum geologist is to determine the character of the original material. It is either a buried liquid oil or a semi-solid wax which, acted upon by natural agencies after burial, gives off the gases and liquids of petroleum. This latter process occurs either during the time of deposition or sometime after the sediments have become buried and hardened. J. Claude Jones[1] gives an interesting account of certain Lake Lahontan sediments which contain traces of petroleum. He suggests that oil shales originate as fresh or brackish water muds, rich in organic matter, where bacterial action was not sufficiently active to raise appreciably

[1] J. Claude Jones, "Suggestive Evidence on the Origin of Petroleum and Oil Shale," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 1 (1923), p. 67.

the relative proportion of fats by removal of other plant substances. Petroleum muds would, according to the same hypothesis, originate in salt waters containing 3,000 parts per million or greater, where the bacterial action had relatively increased the proportion of fats.

Takahashi[1] suggests that the black shales from regions where the rocks are non-productive of oil are different in fossil content and in the nature of the "kerogen" from shales belonging to the oil measure. This would indicate a probable difference between the "kerogen" or bituminous material in marine shales and that in fresh-water oil shales. The fact that Jones observed liquid oil in salt-water shales very soon after deposition, is not entirely conclusive that petroleum is liquid throughout its entire life, for the reason that this apparent liquid oil in oozes might consolidate when buried to form a substance similar in nature to the waxlike material found in marine shales.

If petroleum is the result of liquid oil formed in oozes and remaining as liquid oil throughout its history, there should be more evidence of oil, as such, along the outcrop of marine beds. The marine bituminous shales certainly could not have been drained of all their petroleum and consequently should show oil, as such, quite commonly on the outcrop. This does not seem to be the fact, however, as liquid oil is found, as a rule, in local seeps at the outcrop which are most probably merely eroded oil pools. The fact that oil remains in a sandstone outcrop for thousands of years during erosion, is all the more reason why some oil should have remained in the source beds, since these rocks have finer pores and offer better protection against evaporation than the sandstones.

In summarizing the present knowledge concerning the bituminous material in sedimentary marine beds, it seems that the evidence for widely disseminated liquid oil throughout the probable source rock is lacking, while the evidence is fairly conclusive that there is considerable solid bituminous matter in shales throughout petroleum-bearing zones. It is possible, however, that liquid oil, as such, was buried during deposition of sediment and later collected into commercial pools without undergoing any material change, but

[1] *Op. cit.*, p. 150.

this is still a questionable point and deserves the attention of future chemical and geological research.

If the solid or semi-solid bituminous material in marine shales is the source of petroleum, the question next arises as to how this material has been changed into liquid oil. Heat is a known means by which any of the so-called "kerogen," or torbanite group may be changed into liquid hydrocarbons. However, in the widespread analysis of petroleum deposits there are numerous fields located in great synclinal sedimentary basins where it is difficult to apply the transformation by heat because of the lack of evidence in such places for heat amounting to the necessary 450° F. On the other hand, Washburne has suggested that the chemical action is an exothermic one, and when once started will generate heat to carry on the action. This might apply if the action would start at lower temperatures and continue to function as the generation of oil continued. Tests on oil shales, however, covering periods of several days, by A. E. Brainerd and some similar works by E. A. Trager, have failed to indicate such conditions, but more extensive work of this nature should be done before a definite conclusion can be reached.

If heat cannot be logically and universally applied to explain the transformation of liquid oil from solid bituminous substances, some other mechanical or chemical means (common to all conditions) might be necessary to account for this change. On this basis Trager and the author[1] attempted to experiment with mechanical energy resulting from compression as a means to accomplish the desired result.

The original idea back of this attempt was to learn if mechanical energy or work done upon the solid hydrocarbons in the shale, by a pressure acting through a distance, would cause a similar chemical change to that brought about by heat energy. Upon further consideration, it seemed reasonable to expect the effect of pressure in the production of crude oil, since in the Snelling[2] experiments, pressure was the main factor in forming a synthetic crude oil from

[1] A. W. McCoy, *Journal of Geology*, Vol. 27; Earl A. Trager, "Kerogen and Its Relation to the Origin of Oil," *Bull. Amer. Assoc. Petr. Geol.*, Vol. 8, No. 3 (1924), pp. 301–11.

[2] W. O. Snelling, *A.I.M.M.E.* Vol. 51 (1915), p. 657.

hydrocarbons either of higher or lower hydrogen values. The Snelling experiments show that the ratio of the volume of the original mass at atmospheric pressure to the total closed-in volume of the container is about one in four for successful results. Synthetic crude oil is not formed when the container is completely filled regardless of temperature or pressure. This may indicate the necessity of about three additional volumes of voids in the shale in proportion to the volume of solid hydrocarbons, in order that the molecular rearrangements may take place to form petroleum, during pressure experiments. Since pressure experiments are made with the absence of heat, considerable time might be required for an appreciable change to take place. Laboratory experiments are of very short duration and satisfactory quantitative results might be difficult to obtain. Should this molecular rearrangement be roughly compared to the formation of cyanite, zoisite, or other metamorphic minerals from sediments under great pressure, it could not be expected to occur in quantity during a short interval of time.

The outcome of the pressure experiments previously referred to showed that, while all soluble hydrocarbons were apparently removed before the experiment, and after differential movement had taken place, there was obtained good coloration by dropping particles of the squeezed shale into solvents. Van Tuyl and Blackburn[1] have duplicated these experiments, and have concluded that there is no change in the material due to mechanical action. However, in all of Van Tuyl's leaching tests, the material was ground to pass an 80-mesh screen, and his experiments show that by grinding either before or after compression, approximately one-eighth of the amount of oil obtainable by distillation was leached by solvents. The grinding of the shale to an 80-mesh size causes a greater amount of differential movement to take place in the shale than is possible by merely allowing the shale to bulge slightly in the middle of a cylinder; consequently, grinding, both before and after compression for quantitative tests, might obliterate any appreciable effect of the flowage experiment. A. E. Brainerd[2] has performed the

[1] F. M. Van Tuyl and C. O. Blackburn, "The Effect of Rock Flowage on the Kerogen of Oil Shale," *Bull. Amer. Assoc. Petr. Geol.*, Vol. 9 (1925), p. 158.

[2] A. E. Brainerd, Unpublished manuscript.

same leaching experiments in conjunction with the writer, and found that by continued grinding after the shale has passed even a 200-mesh screen, more soluble material is leachable after each period of grinding. The details of these experiments may be described in an early publication. It appears from Brainerd's work that by continued grinding, rubbing, or pounding, more and more of the so-called "kerogen" becomes soluble in the ordinary solvents. Additional surface exposure for the action of solvents has been suggested as the reason for more coloration after each grinding, but this has been rather definitely disproved by Geo. O. Williams with a series of experiments which indicated that one grinding to an 80-mesh size gave approximately twenty-five times as much leachable material per surface unit exposed as one grinding to a 200-mesh. In none of these tests can heat have been a factor, at least the necessary heat for distillation as known from laboratory experiments. Since the action of changing kerogen to liquid oil is endothermic, it is possible that minute particles of the kerogen might receive considerable heat instantaneously due to friction, and this heat, by being absorbed in the reaction, would not be radiated in such manner as to increase the temperature of the surrounding shale.

It is, of course, obvious that both heat and differential movement may have worked together in a number of localities to produce petroleum, if the solid wax in marine shales is the only source of crude oil. In other districts where the evidence of the necessary heat is absent, it is possible that movement was sufficient to cause some change although quantitative ratios will have to be proved or disproved by further experiments or calculations.

Considering both heat and differential movement as the cause for generating oil from solid hydrocarbons in the shale, it should follow that only in local areas of folding and faulting would there be any consequential amount of oil formed. This would coincide with the field evidence which shows a general lack of liquid oil disseminated throughout the supposed source rock along the outcrop, except in local areas usually associated with some form of movement.

If quantitative ratios of petroleum cannot be shown to have been derived from kerogen by differential movement, and evidence for widespread high temperatures for petroleum provinces cannot be

substantiated, the following condition appears to be the only explanation which satisfies the majority of the data.

Petroleum as a liquid is formed in marine oozes and buried with the sedimentation. As the process of consolidation proceeds, the liquid oil eventually becomes a waxlike substance similar to grahamite or albertite by the action of gases and connate waters. This residue, or waxlike material, is the kerogen now found in marine or fresh-water shales.

In order that oil accumulations should take place, structural conditions would necessarily have to develop in the sediments before the oil became solidified. Such structural conditions would imply the developing of faults and joints which would bring about a proper arrangement for the interchange of liquid oil from the partially consolidated source beds into reservoir sands by the process described in later paragraphs.

When a considerable body of oil was accumulated into a sand so that the gases and water would not have access to each small particle of oil, it would remain liquid throughout great periods of time. Each minute particle of liquid oil remaining in the source beds would be in contact with water and possibly subject to the action of gases so that all of the oil in source rocks would become solid after some considerable time, approximating that of fair consolidation of the rock-structure.

This explanation conforms with the evidence of liquid oil in oozes and only solid hydrocarbons in the supposed source beds of consolidated rock. Drops of oil in goedes, or in fossil casts, might be large enough to resist complete solidification for great periods of time, that is, much longer than the time required to solidify the finely disseminated oil in source rock.

Such explanation further suggests the necessity of differential settling or movement in the sedimentation before complete solidification in order to develop oil accumulation. In other words, provinces where bituminous sediments are deposited in close relation to water horizons would not necessarily develop places of oil accumulation if the beds in the whole area were allowed to completely solidify before structural movements took place. On the other hand, provinces of bituminous sedimentation which are being stressed, such

as to develop faults, joints, and other structural conditions during the deposition of the sediments, or at least before complete consolidation of the rock had taken place, would form many local areas for oil accumulations. This would emphasize the importance of the settling type of structure as most favorable for oil accumulation in areas of bituminous sedimentation in case proper relations of the bituminous beds and water horizons were established soon after deposition. Large folds or faults developed by compression or mountain-making processes after the complete consolidation of the beds would not be the proper places for oil accumulation according to this hypothesis unless structural conditions had begun to develop prior to the complete solidification of the source-bed oil.

This hypothesis concurs with the field evidence in that oil accumulations would occur only in local regions of differential movement, but it would necessitate the initial development of this movement before the liquid oil in the source beds has been solidified to kerogen.

The time of structural development in relation to the rate of hardening of the oil in source rock might be a determining factor in the character of the oil accumulated. Very prompt accumulation after the deposition of the source beds would probably concentrate heavier oil high in sulphur. Accumulations which started some time after part of the liquid oil in source beds had begun to harden would probably result in lighter oil with less sulphur. Gas only might result in accumulation where structural movements were initiated very late in the solidification of the liquid oil in the bituminous strata. Zones of higher carbon ratios are in many places the zones which indicate rapid consolidation, probably accounted for by the better opportunity for drying out and dehydrating along the margins of a basin. In this way, further investigation might eventually harmonize this hypothesis with White's carbon ratio theory and many other facts of observation concerning oil deposits which have previously been recorded.

The determination of the time of structural stresses in relation to the time of deposition becomes of utmost importance in substantiating this hypothesis. Furthermore, it is necessary to establish proof that the action of water and gas commonly associated

with, or developed in, bituminous sedimentation, would solidify the disseminated oil in source rock within some reasonable time, approximating that necessary for nearly complete consolidation of the surrounding beds.

PROCESS BY WHICH OIL MIGRATED INTO SAND OR RESERVOIR ROCK

The second major problem in petroleum accumulation is to consider the means by which oil passes from the fine-grained source beds into the reservoir rock. It is obvious that various amounts of heat and pressure are common to buried strata, and that water is generally associated with oil-bearing formations. These are the natural agencies which most probably cause the universal interchange.

Average temperatures in the present oil-producing zones indicate a range from 60° to 120° F. Since the radiation of heat from zones 1,000 to 5,000 feet below the surface is so extremely slow, it is best not to consider temperatures higher than the present upper limit as it would be difficult to prove that the temperature was ever a great deal more than that now existing in the beds. Increased temperature would have the tendency slightly to expand the oil and, in a less degree, have the same effect upon water. So long as present temperatures underground for oil deposits are not materially different from surface average temperatures, it is difficult to assign any appreciable work to heat in the matter of driving oil into the reservoir rock by expansion.

Pressure would have the effect of squeezing liquid oil from the more compressible (completely saturated) beds into those less compressible, if the less-compressible formations were porous and the pores filled by a substance which is comparatively compressible. For example, settling shales could readily cause a liquid to move into a dry porous sand and the air or gas in the sand would contract in volume according to the invading fluid pressure; but if the sand were completely saturated with water, it would withstand a great amount of pressure before a liquid could enter the sand to any appreciable extent. In the latter case, the compressible beds would tend to act as a hydraulic cushion against pressures much greater than the overburden, at depths less than 6,000 feet.

The questionable point on the importance of squeezing, arises when consideration is given to the time of settling and its relative amounts during the geologic history of the formation. A much greater portion of shale settling comes very soon after, or during, consolidation of the sediments. This is borne out by the fact that fossils and other soft structural forms are not commonly distorted after the rock once consolidates around them, even though the material in which they are embedded is shale, and has been buried under several thousand feet of sediment.

If liquid oil is developed during deposition in sufficient quantities to saturate the source bed, then squeezing the muds would tend to relieve them of their excess fluid and, by this process, oil would be forced into the more porous non-compressible strata, other conditions, as previously mentioned, being favorable. On the other hand, if liquid oil is generated from the solid bituminous material in shales after they have become hardened and consolidated, there seems to be so little chance for enough squeezing of the shale to occur, that it is questionable whether commercial amounts of petroleum would be forced into water-saturated reservoirs by squeezing due to consolidation at such shallow depths. Experiments have been tried as illustrating this method of replacement, by placing oil-soaked mud against water sand and then applying pressure. Although an interchange was accomplished, the results are not conclusive because this change can be brought about without pressure. To get the real effect of squeezing alone, these experiments should be tried with oil and other liquids such as mercury which do not have the same affinity for shale as does water. To insist on such an interpretation of oil-movement by squeezing, the advocate should be required to prove the relative amount of this condensation throughout the geologic history of the oil-source formation and show that the amount of settling is quantitative enough, after the formation of liquid oil, to result in commercial volumes of oil being driven out. In order that this reasoning may take the most favorable attitude toward this hypothesis, it is limited to conditions where oil-saturated strata lie directly in conjunction with reservoir rocks. Such conditions would be rather rare in nature, for often the rich bituminous zones are separated from porous-producing horizons by impervious water-satu-

rated shales or hard impervious cap rocks; consequently, it is thought best, in attempting to arrive at a most probable solution, not to assign relative importance to the possibility of squeezing petroleum from the source bed into the reservoir, until better proof is established that this method is a common and quantitative factor.

The remaining agent, common to all districts for driving oil out of fine-grained bituminous beds into porous strata, is water.

Two methods by which water might work to accomplish this result are, first by circulation method thereby impelling oil along with the moving water, and second, by some method of interchange, due to different physical properties of oil and water.

In order to get the desired action by circulation, water would have to move with some appreciable velocity from points of higher pressure, to points of lower pressure, and in doing so, pass through the bituminous bed. In the majority of cases, this would necessitate movement across bedding planes from coarser to finer-grained strata, and vice versa. Such conditions do not conform to field evidence concerning water-bearing formations. For example, the analysis of water from one horizon commonly differs materially, not only in total solids per quantity, but also in character of soluble salts, from that of another water now present in a formation stratigraphically within a hundred or more feet of the first zone. Further to advocate this hypothesis, one would be required to prove that water, under the conditions of heat and pressure, and with the size of openings existent in oil-bearing formations, could overcome frictional losses and move at sufficient velocity to affect the static position of oil in the source rock.

The differing physical properties of oil and water, which might possibly cause a movement from the source bed, are specific gravity, and various molecular attractions. Specific gravity would tend to float the oil above water if sufficiently large openings occurred. The supposed source beds are usually made up of rock particles approximately 0.01 mm. in size or less, and consequently, the interstices which the oil occupies are much less. By laboratory experiment it can readily be shown that there is no tendency for oil and water to separate in zones of varying specific gravity if the two liquids are mixed in pulverized shale, whose particles are in any way similar

to those of the average bituminous bed. It would be necessary if considering this hypothesis to prove such that specific gravity segregation could take place under the known conditions, by means of established principles of physics.

Various molecular attractions of the different liquids would be expressed in terms of cohesion and adhesion. Cohesion is the force by which molecules of the same substance attract adjoining molecules. Adhesion is the force by which molecules of the one substance attract adjoining molecules of another substance. A common application of these forces is shown when a glass tube of small diameter is partially inserted into a basin of water. The water rises slightly in the tube above the water-level in the basin. The height of this rise varies according to the diameter and material of the tube. Commonly this phenomenon is spoken of as capillarity.

Capillarity is due to two causes: (1) the surface tension of the liquid, and (2) the fact that the molecules of the material composing the tube have an attraction for the molecules of the liquid.

Surface tension is the cohesion of the molecules at the surface of a liquid, which tends to make the liquid contract, and can be expressed by the following formula:

(*a*) $$T=\frac{\pi r^2 hqg^1}{2\pi r \cos a}$$

where T is the surface tension; r equals the radius of the tube; h, the height of liquid standing in the tube; q, the density of the liquid; g, the acceleration of gravity; and a, the angle of contact between the liquid and the tube.

Surface tension is a linear function of the absolute temperature, and that for water can be expressed by

(*b*) $$T=0.21\,(370-t)^{2\,2}$$

where t equals the temperature (centigrade).

Pressure causes some change in surface tension, but presumably small. "For changes in the properties of water induced by pressure of, say, 1,000 atmospheres are usually similar in magnitude and

[1] C. T. Knipp, *Physical Review*, Vol. 11, p. 151.

[2] Johnson and Adams, *Journal of Geology*, Vol. 22, p. 9.

direction to those observed when a relatively small quantity of salt is dissolved in it; and the surface tension of such dilute (.05 N. or less) solutions differs by only a small percentage from that of pure water."[1]

Different substances have different surface tensions which can be calculated by means of formula (*a*) with the necessary observed factors. For example, in contact with air, crude oil at 20° C. has an average surface tension of about 31.7 dynes; water at 20° C., about 81 dynes; and mercury at 20° C., about 540 dynes.[2]

Surface tension also varies with the nature of materials in surficial contact. For example, the surface tension of mercury when in contact with water is different from its surface tension when in contact with air. Water in contact with petroleum has a surface tension probably less than one half its surface tension when it is in conjunction with air.[3]

It is necessary that the molecules of the material in the tube have a positive adhesion, or a repelling force, for the molecules of the liquid, otherwise there would be no chance for surface tension to display itself. When this adhesive force is negative, depression of the liquid in the tube results, as in the case of mercury and glass; when adhesion is positive there is a rise in the capillary tube. If adhesion greatly overbalances surface tension, the liquid surface may spread and the liquid mount up the sides of the vessel, as in the case of some light oils in a porcelain cup.

It is a known fact that when oil-soaked mud is placed against a water-saturated sand, the water moves by some physical means from the sand into the shale, and the oil moves into the sand, disregarding the direction of gravity forces. Cook[4] observed this action to continue over a period of six months. The writer has observed the action continuing regularly for the last eighteen months, having replaced oil from the mud a distance of twenty inches from the sand-mud contact. This action is still in progress. Skirvin[5] has brought

[1] *Idem.*

[2] After G. H. Quincke.

[3] *Idem.*

[4] C. W. Cook, *Society of Economic Geology*, Vol. 18, No. 2, p. 167.

[5] O. W. Skirvin, *Society of Economic Geology*, Vol. 17, No. 6, p. 467.

out a timely objection to this interchange by the argument, "that the surface tension between water and an oily surface is zero or at least very slight, for there was no rise of water within the tube when the walls were wet with only a thin film of oil." The fact that water will not adhere to the inside of an oiled glass tube is not because of zero surface tension, but is because the water molecules do not seem to cut through the oil to come in contact with the glass; this is largely a matter of adhesive power and not surface tension. In the case of oil-soaked shale, the interchange does take place and can readily be observed by an experimenter. There is possibly some difference in the attraction, or adhesion, of shale and water which is apparently stronger than that of glass and water. In the case of sands of unequal fineness this interchange is very slow and in both Skirvins and Van Mills[1] experiments, only sands appear to have been used. If the water is kept at a temperature of 140° F., the water movement to fine sand (80-mesh) driving back the oil to the coarse sand (30-mesh) is very materially hastened, while with water of 50° F. this movement is extremely slow and may never complete a perfect interchange. In the case of oil-soaked shale and water sand, the interchange will occur obviously regardless of lower water temperatures, but apparently increases its rate of movement with the rise in temperature.

In analyzing this phenomenon, it seems that the oil breaks up into very small drops and migrates back through the center of a water passage until it reaches a state of equilibrium in the larger openings of the sand. Since increased temperature accentuates the action, it must be the relative decrease of the forces of surface tension compared with those of adhesion which causes the water to move into the shale, and oil to move back through the water column. The action apparently starts with the adhesion of water for shale particles which causes the water to creep slightly against the oil at the fluid-shale contact (points A and A' in Fig. 1) and a slight differential pressure to develop on the oil as water is drawn from A to B and A' to B'. Then as the creep advances, the difference in pressures P (that on the oil) and P' (that on the water) exceeds the surface tension of the water at T which has been materially lessened by

[1] *Economic Geology*, Vol. 15, No. 5.

being in contact with oil, and the surface of the liquid is broken so that a drop of oil moves into the water capillary to equalize the fluid pressures. Hereafter adhesion displays itself again, so that other drops of oil are forced back into the water capillaries and finally a series of oil drops, or particles, is working toward the sand. Cook's[1] illustrations indicate this method.

The rise in a capillary tube is limited by the pressure on the gas or air in the tube and the weight of the column of fluid raised. In the

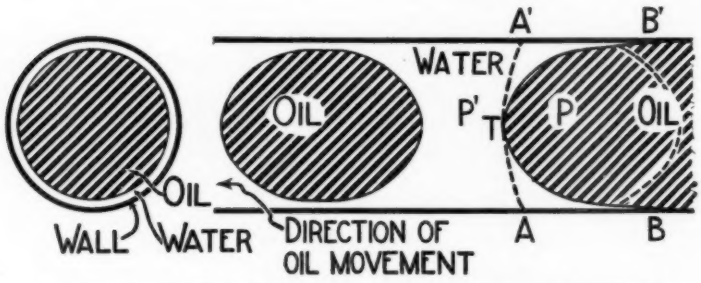

FIG. 1.—Diagram illustrating oil replacement by water in small capillaries

case of oil-water interchange, apparently the surface tension of the water is so reduced as to allow the breaking of the water surface to occur with an interchange of liquids, and pressures again equalized so that adhesion is free to repeat the act. Consequently this phenomenon is not entirely a process of capillarity, and probably it should not be referred to by that term. By breaking the surface of the water and equalizing the fluid pressures, and repeating the action continuously, it appears that this process would have no actual limits in infinite time, so long as the water had oil-soaked shale in contact with it, and there were continuous water connections to the same.

The drops of oil probably do not coalesce in the smaller capillaries, as the film of water between them is too resistant to be broken by such a small mass. Each new oil particle repels those ahead of it in the capillary water column so that the resultant action approaches a current of oil drops passing through a water tube in an opposite direction to the water movement. As these oil drops enter the large

[1] *Society of Economic Geologists, Pub. No. 17.*

openings of a sand body they coalesce to form a miniature pool. Unless this process is stopped by some chemical change at the oil-water contact, there seems to be no reason why such miniature pools might not develop throughout thousands of years to account for major oil accumulations. Water will move from saturated sands through water-wet shale into oil-soaked shale, and if the quantity of oil is great enough compared with the thickness of the water-saturated shale, oil will eventually accumulate in the sand regardless of gravitational forces. The action ceases, however, immediately at any complete break in fluid continuity. The interchange will work around small cavities with equal efficiency, provided fluid is continuous around the cavity.

One suggestion which is brought out by this interpretation of oil and water relations in small openings is that the source beds would have to be fairly well saturated with oil, in order to expect replacement of quantity into the reservoir zones. Small amounts of oil disseminated throughout a shaly horizon when acted upon by water would tend to spread out in a series of drops in water capillaries, and unless there was additional oil-soaked shale immediately adjoining for the water to work on, there would be no reason why these oil stringers would move on toward the sand.

This method of removing oil from the shale seems possible from the brief physical analysis here given. Fluid pressures equivalent to those existing in oil-bearing zones would not materially affect this action, judging by effects of pressure upon cohesion and adhesion. In the same way, salts in solution up to the most saturated brines would not tend to stop this action. Temperature would be the greatest factor to cause variation in the movement, but as the temperature increases, the action would be facilitated because the surface tension of the water would be reduced, and the surface of the water in the replacement process would be broken more readily.

In criticising this method of replacement, it is not enough for any worker merely to state that the process would only act through a few centimeters or that the action is of minor importance, or that this phenomenon is more of a resisting force than a positive action. It is absolutely necessary, in order to discard this possibility as a probable solution, for the investigator to limit the action and to

define its limitations by mathematical and physical proof, substantiated by correct experimental data.

MOVEMENT OF OIL INTO COMMERCIAL POOLS

After oil once reaches the reservoir rock, it either moves on to a new collecting ground, or it never moves materially from the places of entrance in the sand, other than to back up in the more porous parts of the sand to a distance depending upon the quantity of oil moving into the sand at the places of entrance. Oil might move away from the places of entrance in two ways. First, due to the difference in specific gravity of oil and water, the oil might move up the dip until it reaches some structural barrier and there accumulate. Second, circulating waters might carry small particles of oil along in their currents until, having reached points in structural positions where the oil becomes more protected against the currents, or in places of differing porosities, the oil might cease to move and collect into pools.

The first means of moving oil to places of accumulation in the sand as previously stated, is the original anticlinal theory for which all petroleum geologists have a profound respect. However, the questionable phase of this hypothesis arises when attempts are made to duplicate such conditions by placing water and oil in sands with grains of a similar size as most of the producing sandstones of the majority of American oil fields. After numerous experiments with an oil and water mixture in sand grains 0.2 mm. in diameter, it is apparently a fact that the fluids will not segregate on a gravity basis. Then the question of gas to aid in the buoyancy of oil should be considered. The majority of oil and gas bodies underground are under, or have been under, pressures at the time of accumulation from 200 to 1,000 pounds per square inch. In such cases most of the lighter hydrocarbon gases associated with oil are probably in solution in the oil, and consequently the mass of the material is in the form of a fluid and would most probably act according to fluid laws. It is true in laboratory experiments that the addition of gas bubbles below an oil-water mixture in coarser sands does bring about a better gravitational assortment than that accomplished by the oil alone. On the other hand, in finer sands (those more comparable

with the real conditions in nature), gas is not able to assort itself on the gravity basis, without having the additional burden of carrying oil along with it. Considering the many pools throughout North America which probably contained little or no gas, except that as absorbed in the oil at the time of accumulation, and noting the average fine-grained sandstone in which the concentration exists, it is difficult to apply universal weight to gravitational assortment, until definite proof has been established as to the buoyancy forces in the properly sized openings for the majority of cases.

The second method for accumulating oil into pools is that of circulating currents underground, commonly spoken of as the hydraulic theory. It is useless to repeat an explanation of the worthy discussions presented on this question by Messrs. Munn, Shaw, Johnson, Van Mills, Rich, and many others. Assuming what these men have said to be true, provided reasonable circulation of water is commonly taking place in sedimentary beds, there is yet reason to question the primary assumption. First, there must be some place for the water to go, for differences in pressure throughout a water-saturated formation can adjust themselves eventually without any material circulation. Water will not flow in a full pipe line with the lower end closed even if the upper end should be hundreds of feet higher in elevation. Some physical proof is needed to show quantitatively how much water is escaping, or has escaped, from these water-bearing zones. After a definite volume of water is shown to have been taken out of these sedimentary beds, the problem then arises to compute the necessary velocity of the replacing fluid in order to maintain a full supply. Then it follows that the differential water head in nature from the point of intake to the point of relief should be shown to be sufficient to overcome frictional losses in openings of certain size, and account for such velocities. When this is established, the propelling force, which water (moving at said verified velocities) has upon particles of oil in bodies of sand with the proper grain size, should be computed. The established propelling force compared with the frictional resistance of the oil in moving through the sand, results in the actual value of movement.

Until this is thoroughly proved theoretically and substantiated by geological data and physical experiment, it is of minor conse-

quence to discuss the importance of hydraulics in moving oil to its location, as in commercial pools, because the primary assumption has not been verified.

Another method of approach, to show that there has been some oil movement either by the hydraulic or the buoyancy method, would be to prove conclusively that the oil in major commercial pools could not have entered the sand at those places. If neither this condition can be shown false, nor the possible movement accounted for by application of physical laws, applied to the existing conditions in nature, it is then essential to consider that the majority of commercial oil pools are intimately associated with the places where the oil first entered the sand.

CONCLUSIONS

There are no particular conclusions to be set forth by this discussion other than to state that the paper is written with the idea of bringing out discussion which may assist in leading to a final solution of the problem. At least by encouraged research along these lines, it will eventually be possible completely to discard some hypothetical assumptions and gradually to bring conclusions nearer the true condition.

THE EFFECT OF GRAVITATIONAL COMPACTION ON THE STRUCTURE OF SEDIMENTARY ROCKS

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ABSTRACT

Many oil field structures have been attributed either to lateral variation in the compressibility of sedimentary strata or to the settling of sediments over buried hills. So far few or no experimental data have been published as a basis for such theories. In recognition of this need, a study is made of the compressibility of clays and shales, and a table is obtained showing the relation of the porosity of shale to the overburden. The amount of closure due to the settling of mud or shale over a hill 100 feet high is then calculated, and the character of structures produced by vertical compaction is outlined. As a practical application of these quantitative data two areas in Kansas are considered. Finally, the porosity of argillaceous sediments is suggested as an index of pressure metamorphism.

INTRODUCTION

The fact that sediments are compacted under the influence of their own weight has long been a commonplace, and even as early as the seventeenth century Steno recognized that variations in the attitude of sedimentary strata might be due to settling. However, the possible economic importance of the phenomenon was scarcely realized until some ten years ago, when the idea of the differential compressibility of sedimentary rock types was offered as an explanation of certain anomalies of structure in the mid-continent petroleum region.

Early suggestions of the possible importance of compaction as a source of folding aroused widespread interest, and now many writers have given the subject consideration and many oil field structures have been attributed either to lateral variation in the compressibility of sedimentary strata or to the settling of sediments over buried hills.

Elemental expositions of the theory in its different phases of application have been given by Blackwelder,[1] Lahee,[2] Teas,[3] Mon-

[1] Eliot Blackwelder, "The Origin of Central Kansas Oil Domes," *Bulletin American Association Petroleum Geologists*, Vol. 4 (1920), pp. 89–94.

[2] F. H. Lahee, *Field Geology* (1923), pp. 168–71.

[3] L. P. Teas, "Differential Compacting, the Cause of Certain Claiborne Dips," *Bulletin American Association Petroleum Geologists*, Vol. 7 (1923), pp. 370–77.

nett,[1] and others. Among oil field structures which have wholly or partially been attributed to differential compaction are the folds of southeastern Kansas and those of the El Dorado, Peabody-Elbing, and Russell fields, in Kansas; Cushing, Pershing, Healdton, and Garber, in Oklahoma; Goose Creek and Amarillo, in Texas; and Smackover, in Arkansas.

That major dips and folds may be produced during the settling of sediments is now generally admitted; however, the principles involved have been invoked repeatedly without quantitative data on the actual effectiveness of the process. It has been recognized that muds, silts, and deposits of organic matter may suffer considerable compaction, whereas sandstones, limestones, and igneous and metamorphic rocks are relatively incompressible, but the amount of condensation which is possible in these rocks is only vaguely known. This lack of definite data becomes especially evident when considering the estimates which have been made of the potential vertical shrinkage of different types of sediment. For instance, vertical shortening in the case of sand has been variously placed between 1 and 25 per cent, while in the case of muds, estimates range from 15 to 90 per cent. It is apparent that until more definite figures are obtained for these sediments it is impossible to evaluate with any assurance of accuracy the rôle played by compaction in the production of specific oil field structures.

The mechanical means by which shrinkage takes place in sediments and the factors which are effective in causing such shrinkage have also been variously interpreted. Is time an important factor in the process? Are lateral crustal forces relatively more important in producing compaction than pressure due to rock overburden? Is the reflection of buried hills in overlying strata projected through unconformities of major importance? What is the effect of accumulating sediment in masking the reflection of a buried hill or sand lens? What influence have earth tremors and minor earth movements on the settling of sediments? And finally, what is the quantitative relation between gravitational pressure and vertical shortening? Upon the answers to these and similar questions depends the extent to

[1] V. E. Monnett, "Possible Origin of Some of the Structures of the Mid-Continent Oil Field," *Economic Geology*, Vol. 17 (1922), pp. 194–200.

which compaction may be held responsible for structural deformation in any region.

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THE COMPACTION OF SEDIMENTS

The lithification and induration of sediments almost always results in volume shrinkage and increase of rock density. Exception must occasionally be made in the case of polymorphic substances, such as $CaCO_3$, where the change from aragonite to calcite is accompanied by a decrease in density, and in a few cases where the rock undergoes a change in chemical composition, as in the alteration of anhydrite to gypsum. It also seems possible that cementation by infiltration may sometimes cause an increase in rock volume. The compaction which normally accompanies lithification is accomplished chiefly by decomposition, recrystallization, and elimination of pore space.

Decomposition.—One of the best known and most striking instances of compaction results from the volatilization of organic matter. It is estimated that from 15 to 30 feet of peat are required to produce 1 foot of coal, and Ashley[1] estimates that at a depth of 15 or

[1] G. H. Ashley, "The Maximum Rate of Deposition of Coal," *Economic Geology*, Vol. 21 (1907), p. 43.

20 feet, 1 foot of surface peat will have been reduced to $1\frac{1}{3}$ inches of compressed peat. This reduction in volume is accomplished not primarily by increase in density, but by decomposition with the evolution of volatile gases.

Where vegetable accumulations have occurred in basin-like depressions, subsequently covered by sediment, the original contours of the basin must often be clearly reflected in the structure of the overlying strata. As inorganic impurities in the vegetable matter increase, the percentage loss of volume due to volatilization will decrease, but even in the case of carbonaceous shales much vertical shrinkage must have taken place as a result of the decomposition of organic matter, of which only the less volatile residue now remains.

Recrystallization.—Most minerals are only very slightly compressible. According to Leith,[1] "the compressibility of diamond and quartz per megabar at 0 megabars is, respectively, .18 and 2.7 parts in 10,000,000." However, pressure does help to bring about recrystallization with the formation of minerals of higher density. Leith and Mead[2] give 2.68 as the average mineral density of clay; 2.71, for shale; and 2.7 to 2.85, for slate; and estimate the average volume decrease due to mineralogical changes in the passage from clay to shale as only 1.5 per cent. In regard to the change from shale to slate, Leith and Mead say, "Comparison of the analyses of slates and shales shows also that in the change from one to the other there has been slight, if any, elimination of water, carbon dioxide, and oxygen; hence there is practically no diminution of volume from this cause. The total change in volume, therefore, is essentially measured by the diminution of porosity. . . . ."

Recrystallization as a result of diastrophic forces is evident in the formation of slates and schists and the development of flow cleavage in folded strata. Moreover, Hutchings[3] found that much white mica was developed in the early stages of the lithification of clays, and Leith and Mead[4] think that "deep burial of a clay or

[1] C. K. Leith, *Structural Geology* (1923), p. 307.

[2] C. K. Leith and W. J. Mead, *Metamorphic Geology* (1915), pp. 101–20.

[3] W. M. Hutchins, "Clays, Shales, and Slates," *Geological Magazine*, Vol. 3 (1896), p. 347.

[4] C. K. Leith and W. J. Mead, *op. cit.*, pp. 101–20.

shale formation may develop a highly crystalline rock, mineralogically and chemically allied to the slates."

Elimination of pore space.—While recrystallization and decomposition may be effective under certain conditions and with certain kinds of sediment, compaction of the major types of sedimentary rocks is accomplished chiefly through the reduction of intergranular pore space. The initial porosity of sediments, the means by which pore space is reduced, and the forces involved in this reduction will be discussed separately in succeeding sections.

INITIAL POROSITY OF SEDIMENTS

The initial porosity of a sediment depends chiefly on the grain size, shape, mode of packing, and degree of uniformity.

Theoretically, the size of grain should not affect porosity. A mathematical calculation shows that a sand of spherical grains 1 mm. in diameter should have the same porosity as a similar sand with grains of diameter .01 mm. Practically, however, if space in the sand occupied by air, water, or any other mobile medium is considered pore space, the second sand will show a greater porosity than the first. This is due to the fact that solid surfaces adsorb thin films of gases or liquids, the quantity adsorbed being proportional to the surface area of the solid. The greater the degree of subdivision of a given volume of solid, the greater its specific surface or ratio of surface area to volume of grain. Consequently, in finely divided substances the effects of surface phenomena, such as adsorption, become very pronounced. Thus, a grain of sand 1 mm. in diameter has a surface area of 3.14 sq. mm., while the same volume of sand reduced to spherical particles of a diameter of .001 mm. has a surface area of 3.14 sq. m. The effect of the adsorbed film on porosity is negligible where specific surface is small, but where large, as in fine powders, porosity is tremendously increased. Thus Bancroft[1] quotes data showing that a very adsorptive substance, such as carbon black, may have a porosity of as much as 95 per cent, and determinations on indigo powder have shown a porosity of 80 per cent.

Similarly, in the case of natural sediments, a fine-grained sediment, such as mud, will carry down a much larger amount of ad-

[1] W. L. Bancroft, *Applied Colloid Chemistry* (1921), p. 21.

sorbed water than an equal volume of sand or coarser sediment. As volume occupied by chemically uncombined water is here considered pore space, the factor of grain size alone is sufficient to explain a much higher porosity for mud than for sand. Moreover, mud particles are usually flat, while sand grains approach a rounded form more frequently, and, as a flat particle has a larger specific surface than a spherical one of the same volume, the importance of adsorption in muds is thus further increased. In addition to surface area, adsorption depends also on the mineral character of the adsorbing substance and the composition, temperature, pressure, and physical state of the adsorbed substance.

The maximum calculated porosity for spherical grains of uniform size is 47.6 per cent, and the minimum, 25.9 per cent. Muds and clays, in addition to being fine-grained, have a notably large proportion of thin, platy particles of micaceous character. If these unequidimensional grains assume similar orientation, porosity, neglecting the effects of adsorption, may be reduced far below the minimum for spheres; on the other hand, with dissimilar orientation it is possible to obtain with such grains a porosity much greater than the maximum for spheres.

In water affected by wave or current action the position of maximum equilibrium for unequidimensional grains will be found with broad sides parallel to the depositional surface. Likewise, in free settling in quiet water particles will tend to assume a position such that their broad faces are horizontal. Such an orientation should lead to much less than the maximum porosity if arrangement of particles were the determining factor. However, a 50-grain sample of white South Carolina kaolin which had been passed through a 200-mesh sieve showed a porosity of 88.8 per cent for the dry clay loosely aggregated. After shaking and jarring the container the porosity was reduced to 81 per cent. The same clay was then thoroughly shaken in a liter of water and allowed to settle until an equilibrium was reached which was not disturbed over a period of several days. The porosity of the water-deposited clay was 84.4 per cent. These figures are illustrative of the effects of adsorbed air and water on the porosity of fine-grained sediments.

Experiments were conducted in the laboratory to determine the

initial porosity of various sediments. Twenty-gram samples of ten different pulverized clays and shales were deposited in 100-cubic centimeter graduates and the porosities calculated after settling was so complete that several days failed to show any further change in volume. The porosities of these deposits ranged from 77.2 per cent, for a slightly sandy Pennsylvanian shale, to 89.5 per cent, for a Comanchean black shale. It is doubtful if these figures are representative of the true initial porosities of the shales in question, as it is impossible to restore a consolidated clay or shale to its original condition. It should also be borne in mind in considering these figures that porosities must always be expressed as averages for a column of sediment of a certain length. For instance, in the previously mentioned cases where 20-gram samples were used, the length of the column was 3 or 4 inches. If the porosity had been determined for the upper inch of this column only, the figure obtained would have been considerably higher. Where larger samples were used the calculated percentage of porosity was less, since the average was brought down by the increased compression of the lower part of the column.

Sediments deposited under natural conditions will in general have lower porosities than the same material deposited in quiet water in the laboratory, as waves and currents tend to shift particles toward an arrangement of maximum compactness. However, Shaw[1] found that the water content of different recent mud deposits along the sea coast ranged from 40 or 50 per cent to more than 90 per cent. Meinzer[2] quotes Shaw to the effect that "much of the newly deposited material of the Mississippi delta has a porosity of 80 to 90 per cent." And Lewis[3] mentions that "engineers of the Interstate Bridge and Tunnel Commission have collected samples of semiliquid mud from the bottom of the Hudson near Canal Street, New York City, which contained by volume 77.15 per cent to 88.4 per cent water; and mud deposited on a crate suspended from Erie Railroad

[1] E. W. Shaw, "The Rôle and Fate of Connate Water in Oil and Gas Sands," *Am. Inst. Min. Eng. Bull. 103* (1915), p. 1451.

[2] O. E. Meinzer, "The Occurrence of Ground Water in the United States," *U. S. Geol. Survey Water Supply Paper 489* (1923), p. 8.

[3] J. V. Lewis, "The Fissility of Shale and Its Relation to Petroleum," *Bulletin Geological Society of America*, Vol. 35 (1924), p. 563.

Pier No. 9, Jersey City, yielded by weight 73.67 per cent water, or by volume, 88.18 per cent."

A 20-gram sample of loess, deposited in the laboratory under the same conditions as the shales and clays previously mentioned, showed an initial porosity of 63.1 per cent. Air-dried loess from Illinois showed a porosity of 47 per cent, and air-dried alluvium from Missouri River, near St. Louis, contained 43 per cent pore space. Determinations made by C. H. Lee[1] on thirty-six samples from the alluvium of the major stream valleys of San Diego County, California, in their natural state of compactness, showed the following results: coarse sand, 39–41 per cent porosity; medium sand, 41–48 per cent; fine sand, 44–49 per cent; fine sandy loam, 50–54 per cent.

REDUCTION OF PORE SPACE

Although immediately after deposition muds may have porosities of 70 to 90 per cent, silts from 50 to 70 per cent, and sands from 30 to 50 per cent, the porosities of shales and sandstones are rarely above 30 per cent, and are usually much lower. This reduction in porosity is accomplished largely by (1) closer packing of particles with elimination of interstitial water, (2) granulation and deformation of particles, (3) recrystallization, and (4) cementation and secondary growth.

In a fresh subaqueous deposit the pore space of the sediment is entirely filled with water, hence only by expulsion of this water can porosity be reduced. Part of the contained water is held by gravity in the larger interstices; another part is held by adsorption as a film about each grain or particle. In a coarse sediment the adsorbed water is of minor importance, but, as discussed above, with increasing subdivision, adsorption becomes relatively more important, and sediment of colloidal dimensions may take up many times its volume of water. The air shrinkage of commercial clays, which may, exceptionally, be as high as 15 per cent;[2] is a result of the dehydration of colloidal matter in the clay by vaporization of the water. As evap-

[1] A. J. Ellis and C. H. Lee, "Geology and Ground Waters of the Western Part of San Diego County, California," *U. S. Geol. Survey Water Supply Paper 446* (1919), pp. 121–23.

[2] H. Ries, *Clays: Occurrence, Properties, and Uses* (1908), p. 157.

oration is largely limited to the surface of the earth, pressure becomes the most potent factor in the dehydration of colloidal sediments below the ground water level.

It is well known that the porosity of a quantity of spherical grains can be changed by more than 20 per cent depending on the arrangement of the spheres. Similarly, for irregular-shaped grains, change in porosity may be induced by changes in the mode of packing. Alteration in the arrangement of grains in any sediment subsequent to deposition will generally be toward the production of the densest system of packing, as this will offer the position of maximum equilibrium with respect to the force of gravity.

Porosity may be reduced by the flattening of soft grains under pressure or by the granulation of fragile grains in such a way that very small particles come to fill the cavities between the larger ones. Thin sections of shaly sandstones frequently show a bending of chloritic and micaceous minerals around the more rigid grains of quartz. Recrystallization under pressure, with the development of unequidimensional crystals, in addition to a slight reduction of volume due to increased mineral density, may also result in a closer packing of grains.

Infiltration, or the filling of cavities by deposition from solution, is, of course, frequently an important means by which pore space may be reduced. The effectiveness of this process will depend on conditions of subsurface water circulation, the character of the strata, and the composition of the ground water.

FORCES EFFECTIVE IN REDUCING PORE SPACE

Lateral pressure.—To most processes by which porosity is reduced, pressure is a necessary adjunct. The effectiveness of pressure due to diastrophic forces is amply demonstrated in the low porosity of slates and other metamorphosed sediments in closely folded regions. However, since it is the horizontal component of these forces which is operative in the reduction of pore space, such pressure results in lateral, rather than vertical, shortening of strata. The effects of tilting due to vertical uplift are much less pronounced and are believed to have been of negligible importance in diminishing porosity where the inclination of beds is slight.

Gravitational pressure.—Although tremendous pressures are undoubtedly generated during diastrophism, the areas of disturbance are of relatively limited extent, and the characteristic incompetence of sedimentary rocks does not permit the transmission of stress over great distances through these strata. On the contrary, gravitational pressure is everywhere important, and in those regions which have suffered little or no diastrophism, it is certainly the dominant factor in the compression of sediments. Its magnitude at any point depends directly on the density and thickness of the overlying rock. Thus, a sedimentary rock of average density, 2.3, will exert a pressure of about 1 lb. per square inch for every foot of rock. At a depth of 10,000 feet in sedimentary strata the pressure must then be considerably more than 10,000 lb. per square inch.

Minor earth movements.—The factors discussed by Lewis[1] as playing an accessory part in the production of fissility in shale are likewise effective in the reduction of pore space. These forces, such as earth tides, variations in atmospheric pressure, impact of waves, and earthquakes, acting in conjunction with gravity, must be important in bringing about a more compact arrangement of particles during the early stages of consolidation of sediments.

Influence of time.—The possible importance of time as a factor in the compaction of sediments has been suggested by several writers. It is recognized that the passage of water through fine-grained sediment is very slow, and that settling continues over long periods. Even in the laboratory the influence of time is notable. Thus 32 cc. of English kaolin, deposited from suspension in water, required a week to reach such a state of equilibrium that further shrinkage could not be measured over a period of several days. A sandy residual clay from Vermont required only three days to reach a similar state of equilibrium.

The time required for natural sediments under constant pressure to reach approximate hydraulic equilibrium, represented by the balancing of hydrodynamic pressure due to weight of overburden by frictional forces tending to prevent the escape of water, is difficult

[1] J. V. Lewis, *op. cit.*, p. 573.

to determine. Terzaghi[1] has arrived at conclusions, expressed in thousands of years, as to time-settlement relations in the case of semisolid clays under relatively small overburden. Under high pressure permeability may be greatly reduced, but even so it seems reasonable to suppose that in natural sediments approximate hydraulic equilibrium is reached in less time than that involved in the average geologic period.

In the case of relatively unconsolidated sediments time is also of importance in so far as greater periods of time allow more perfect granular rearrangement to be brought about by the continually recurring minor earth movements before mentioned. The time required for bending and granulation of particles is probably dependent only on the rate of escape of water from the pores to accomodate this deformation. Finally, it must be admitted that, theoretically, as long as cavities remain in a rock under pressure there will always be a tendency for recrystallization to fill these pores, either through molecular readjustment toward a state of maximum equilibrium or by solution of particles at points of contact and deposition where pressure is lower. However, the high porosity of some ancient sandstones seems to indicate that this process is of little importance.

The Cambrian strata of central Russia were thought to furnish interesting evidence upon the effect of time on consolidation. These sediments, by their fossil content, show that they belong to oldest Paleozoic time; yet they are described as consisting largely of unconsolidated blue clay and other partially consolidated sediments.[2] If this is so, the most plausible explanation of their character is that they have been protected from the effects of crustal disturbances and have never been covered by any great thickness of younger rock. However, Raymond,[3] in his report on the Ordovician of Russia, ex-

[1] Charles Terzaghi, "Principles of Soil Mechanics—Settlement and Consolidation of Clay," *English News-Record*, Vol. 95 (1925), pp. 874–78.

[2] F. Schmidt, "On the Silurian (and Cambrian) Strata of the Baltic Provinces of Russia, etc.," *Quarterly Journal Geological Society of London*, Vol. 38 (1882), pp. 516–17.

[3] P. E. Raymond, "The Correlation of the Ordovician Strata of the Baltic Basin with Those of Eastern North America," *Harvard College Museum Comparative Zoölogy Bulletin 56* (1916), p. 185.

presses the belief that the unconsolidated clay is only the weathering product of an easily altered Cambrian clay shale.

CONSOLIDATION OF THE PRINCIPAL SEDIMENTARY ROCK TYPES

The lithification of sand is accomplished chiefly through cementation by infiltration. In the early stages of consolidation, gravitational pressure and minor earth movements may bring about considerable compaction through the expulsion of excess water and the closer packing of grains. Cementation, however, opposes the operation of these factors, and their effectiveness is limited by the rapidity with which the grains become permanently bound together. From an initial porosity of more than 40 per cent, the pore space of sands may be reduced to 5 per cent or less by infiltration. Data on the porosity of oil sands, determined by Melcher,[1] are illustrative of the wide variation in the porosity of sandstones. Thus the Bartlesville sand in Oklahoma ranges from 7.6 per cent to 38.7 per cent, the sands of the Burbank field show porosities between 6.1 and 32 per cent, and the Newcastle sand of Wyoming ranges from 8.8 to 26 per cent.

Compaction involved in the formation of limestones from unconsolidated calcareous sediment is similar to that which takes place in the case of sands and muds in so far as limestones may have originated in lime sands and lime muds. However, due to the relatively great solubility of calcium carbonate in waters carrying carbon dioxide, calcite cement is usually added to the original particles soon after deposition, and thus the deposit loses pore space and becomes lithified without suffering a great amount of vertical shrinkage. Subsequent alteration of limestone to dolomite may later increase its porosity.

The consolidation of muds and clays is accomplished chiefly by compression. The pore spaces are so minute that there is little free circulation of water, and, consequently, little cementation by infiltration. The first stage in compaction is marked chiefly by elimination of excess pore water and dehydration of colloids, accompanied by a rearrangement of particles toward a mechanical structure of

[1] A. F. Melcher, "Texture of Oil Sands with Relations to the Production of Oil," *Bulletin American Association Petroleum Geologists*, Vol. 8 (1924), p. 716.

maximum density. Further compaction is accomplished by deformation and granulation of soft grains. Recrystallization must continue to some extent throughout the whole course of consolidation.

The whole process of compaction in water-deposited fine-grained sediment must depend to a large extent on the facilities for the escape of connate water. The water content is determined by the equilibrium between the forces tending to hold it in the sediment and the pressure due to weight of overlying strata. Assuming that these forces are in equilibrium at a certain moment, the further addition of sediment at the top of the column will disturb the equilibrium, which can only be restored by the escape of water. In a perfectly homogeneous series migration of the excess water will be upward to a point of lower pressure. However, if more permeable beds are interstratified with the fine-grained sediment, the readiest relief from pressure may be downward to the coarse-grained bed and then upward to the surface along bedding planes. In other cases water may escape laterally or by diverse routes, depending on rock structures. The influence of this great movement of water on the accumulation of oil has been discussed by Shaw,[1] Rich,[2] Lewis,[3] Parks,[4] and others.

CHANGE IN POROSITY AS AN INDEX OF VERTICAL SHORTENING

Pore space in the common sediments, then, may be reduced in two principal ways: by filling of the pores with foreign matter, and by compaction of the original rock material. The first is effective in the case of sands and calcareous deposits, but only slightly so in argillaceous sediment. The second is effective to some extent with all sediments, but chiefly in muds, clays, and shales. The first causes no decrease in rock volume; the second is accomplished only with such decrease.

[1] E. W. Shaw, *op. cit.*, pp. 1449–59.

[2] J. L. Rich, "Moving Underground Water as a Primary Cause of the Migration and Accumulation of Oil and Gas," *Economic Geology*, Vol. 16 (1921), pp. 347–71; "Further Notes on the Hydraulic Theory of Oil Migration and Accumulation," *Bulletin American Association Petroleum Geologists*, Vol. 7 (1923), pp. 213–36.

[3] J. V. Lewis, *op. cit.*, pp. 583–86.

[4] E. M. Parks, "Migration of Oil and Water: a Further Discussion," *Bulletin American Association Petroleum Geologists*, Vol. 8 (1924), p. 697.

Compaction of sediment without addition of foreign matter is brought about chiefly by pressure, aided to some extent by minor earth tremors and vibrations. The source of this pressure may be diastrophism or it may be the weight of overlying rock. The effect of diastrophic forces in reducing pore space is manifested largely in the lateral compaction of sediments. Pressure due to the weight of overlying sediments acts vertically, and reduction of pore space due to this pressure results in vertical shortening of beds. Evidence seems to indicate that diastrophic forces are not transmitted laterally over great distances in relatively incompetent sedimentary rocks, and that the lateral component due to gentle tilting is insignificant as compared with the vertical stress. It therefore seems logical to conclude that in regions where there is little or no evidence of diastrophism, the porosity of beds of mud, clay, and shale may serve as an index of the vertical shortening which these strata have undergone.

In order to arrive at the relation between overburden and vertical shortening of strata it is necessary to evaluate the effect of pressure on porosity. Quantitative estimates of the average porosities of muds and shales under different pressures may be based on data obtained by experimental compression in the laboratory or on the porosities of natural argillaceous sediments which have suffered compression under the weight of known overburdens.

EXPERIMENTAL COMPRESSION OF SEDIMENTS

In order to determine the effect of pressure on the porosity of muds and clays during the early stages of consolidation graduated tubes of glass 3 inches in diameter and 5 feet long were filled with water and sediments were deposited in them. From the volume relations the initial porosity of the clay was calculated after all appreciable settling had ceased; then other sediment, and finally shot, were added, first in increments of 100 gs., and later by kilograms. After each addition the sediment was allowed to settle for a few days until apparent equilibrium was reached, when the volume was measured and porosity calculated. Figure 1 illustrates the relations between pressure and porosity up to pressures of 9 lb. per square inch, as calculated from the weight of the shot added. The rapid

flattening of the curve with increasing pressure is noteworthy, but is probably considerably exaggerated, as the plotted pressures are based on the weight of the shot used, and do not take into consideration the rapid increase in fiction within the tube as the load is increased.

Experiments by Terzaghi[1] afford interesting information regarding the decrease of porosity in clays and sands under pressures up

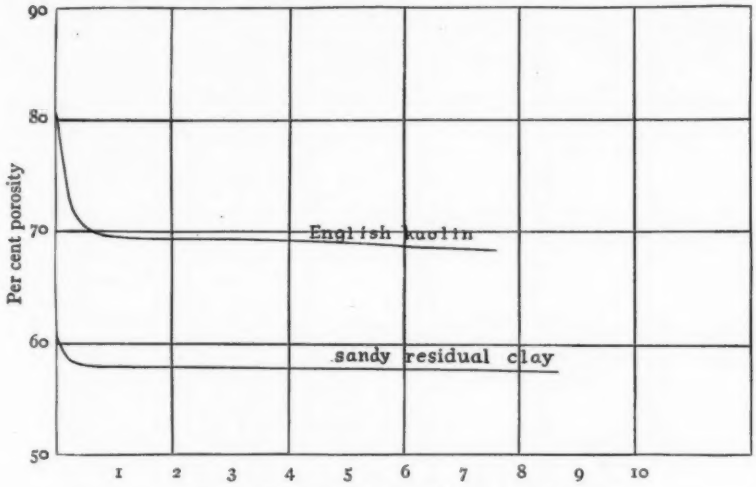

FIG. 1.—Overburden in pounds per square inch

to three or four hundred pounds per square inch. Figure 2 shows approximately the results obtained by Terzaghi. The curves shown in this figure were constructed from graphs by Terzaghi in which void ratios were plotted as ordinates, and pressures in kilograms per square centimeter, as abscissae. Terzaghi's data were largely obtained by compression of layers of sediment 1 cm. thick under pressures of 2, 4, 8, 14, and 20 kgs. per square centimeter. The pressure was applied by means of a "testing machine" on sediment contained in a bronze cylinder. Water was allowed to escape from the sediment through layers of filtered paper supported by a sand filter, and two

[1] Charles Terzaghi, "Principles of Soil Mechanics: Phenomena of Cohesion of Clay," *English News-Record*, Vol. 95 (1925), pp. 742–43, 988.

days' time was allowed for the sediment to reach equilibrium after each increment of pressure. Porosity was calculated at different pressures by determining the change in weight of the sediment and consequently its loss in water.

More data from the laboratory on the change in porosity of sediments under high pressure would be very interesting as a check on other methods of determining this relation. However, passing over the mechanical difficulties involved in making accurate determinations of such a nature, the fact remains, as in all experiments which attempt to simulate natural processes, that results could not

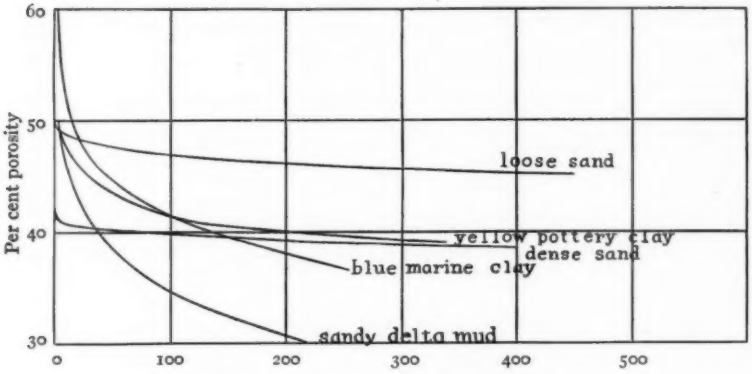

FIG. 2.—Pressure in pounds per square inch

be considered conclusive, as all the factors effective in nature could not be duplicated. For instance, it would be difficult to evaluate the time factor, which is unquestionably important when such processes as recrystallization and the escape of water from fine-grained sediment are considered. The effect of minor earth movements would not be shown. Water conditions similar to those obtaining in nature could not be reproduced, and data obtained for a necessarily short column of sediment would probably apply only imperfectly to greater thicknesses.

POROSITIES OF NATURAL SEDIMENTS

The derivation of the true relation between pressure and porosity from the porosities of natural sediments involves the difficulty of

making allowances for decrease in porosity due to lateral compaction and to variation in the type of sediment and the difficulty of correctly estimating overburden. The effects of lateral compaction may be largely avoided by using samples from areas of little or no deformation, and when samples are taken from a vertical succession,

TABLE I

POROSITIES OF OUTCROP SAMPLES

Formation, Age, and Locality	Rock Density	Mineral Density	Percentage of Porosity
Hamilton shale; Devonian; Hannibal, Mo.	2.321	2.618	11.33
	2.321	2.624	11.57
Basal Pennsylvanian; white flint clay, Fulton, Mo.	2.362	2.627	10.09
	2.373	2.638	10.05
Cherokee shale; Pennsylvanian; Fulton, Mo. (weathered)	2.288	2.769	17.19
	2.293	2.764	17.03
Chanute shale; Pennsylvanian; Independence, Kan.	2.309	2.718	15.03
	2.317	2.720	14.84
Weston shale; Pennsylvanian; Bonner Springs, Kan.	2.277	2.682	15.52
	2.286	2.714	15.98
Wellington shale; Permian; Salina, Kan. (calcareous)	2.396	2.829	15.31
	2.391		15.49
Black shale from Mentor beds; Comanchean; Falun, Kan.	2.050	2.659	22.89
	2.069	2.697	23.29
Graneros shale; Upper Cretaceous; Hamilton County, Kan. (may be slightly weathered)	1.983	2.649	25.16
	1.989	2.637	24.57
Middendorf white clay; Cretaceous; Aiken County, S. C.	1.595 (av)	2.614 (av)	38.97
Mittendorf white clay; Cretaceous; Richland County, S. C.	1.509 (av)	2.617 (av)	42.34
Alloway clay; Miocene; Yorktown, N.J.:			
Blue clay, depth, 13 ft	1.679	2.734	38.59
Yellowish clay, depth 11 ft	1.616	2.707	40.32
Yellow clay, depth, 4 ft	1.302	2.705	51.87
Cohansey clay; Mio-Pliocene; Crossley, N.J.	1.679	2.647	36.57
	1.657	2.646	37.39
Loess; Pleistocene; Collinsville, Ill.	1.455	2.722	46.56
	1.420	2.696	47.33
Missouri River alluvium; Recent; St. Charles County, Mo. (air dried)	1.551	2.697	42.34
	1.526	2.692	43.32

such as is represented by the cuttings from oil wells, the difficulty of correctly estimating overburden is considerably lessened. The fact that variations in the character of the sediment produce variations in its porosity makes it necessary to use samples of uniform type. Thus the conclusions reached were based largely on gray, non-arenaceous, non-calcareous, shales. Data on outcrop samples, unless

otherwise indicated, represent fresh materials, usually obtained from mines, quarries, and shale pits.

Determinations were made of the apparent or rock density and

TABLE II

POROSITIES OF SHALE, WELL CUTTINGS

Well, Locality (Sec. T., R.), and Depth in Feet	Rock Density	Mineral Density	Percentage of Porosity
Ranson well, 5–26–41, Hamilton County, Kan.:			
Graneros shale outcrop	1.983	2.649	25.16
	1.989	2.637	24.57
3,029–40	2.388	2.702	11.62
3,945–50	2.358	2.596	9.17
	2.348	2.637	10.98
4,485–95	2.407	2.644	8.96
4,797–4,805	2.523	2.791	9.62
4,994–5,006	2.448	2.683	8.71
5,355–60	2.526	2.744	7.94
	2.523	2.754	8.38
5,437–40	2.521	2.743	8.09
Phillips well, 3–13–13, Russell County, Kan.:			
1,400	2.146	2.750	21.99
	2.146		
1,485	2.169	2.784	22.06
	2.120	2.765	23.33
2,575	2.304	2.795	17.57
	2,310	2.767	16.53
Lynn well, 10–33–17, Montgomery County, Kan.:			
Chanute shale, outcrop at Independence, Kan.	2.309	2.718	15.03
	2.317	2.720	14.84
500–506	2.476	2.750	10.57
	2.459	2.758	10.22
975	2.514	2.738	8.19
	2.574	2.777	7.32
1,300–1,305	2.548	2.744	7.14
	2.504	2.736	8.45
	2.533	2.740	7.55

of the true or mineral density, and the porosity was calculated from the relation:

$$1 - \frac{\text{rock density}}{\text{mineral density}} \times 100 = \text{percentage of porosity.}$$

The methods employed were similar to those used by Melcher.[1] Rock density was determined by coating a sample of known weight

[1] A. F. Melcher, "Determination of Pore Space of Oil and Gas Sands," *Trans. Am. Inst. Min. Eng.*, Vol. 65 (1921), pp. 469–77.

TABLE III

PREVIOUSLY PUBLISHED DATA ON THE POROSITIES OF MUDS, SHALES, AND ASSOCIATED SEDIMENTARY ROCKS

A*

	Percentage of Porosity
Slate, Penrhyn	0.24
Slates, Westmoreland (three determinations)	0.49
Slate rocks, Hele (two determinations)	2.40
Slate rocks, Moffat (four determinations)	3.60
Coal measure shales (five determinations)	13.2
Coal measure shales, Nottingham:	
510 ft	13.4
829 ft	14.6
1190 ft	10.7
Gault, shale	24.0
Liassic clay (three determinations)	24.4
Bowlder clay (five determinations)	24.8
Tertiary clay	28.8
Alluvial clay	32.0
Clay from old lake at Sewerby	49.5

* H. C. Sorby, "On the Application of Quantitative Methods to the Study of the Structure and History of Rocks," *Quarterly Journal Geological Society of London*, Vol. 64 (1908), pp. 228–31.

B†

Hard bluish-gray shale overlying Keener sand (Miss.); depth, 1,445 ft., Monroe County, Ohio	9.7
Light bluish-gray shale overlying Keener sand (Miss.); depth, 1,475 ft., Monroe County, Ohio	11.0
Ohio shale, Irvine Oil field, Estill County, Ky	7.6 7.4
Greenish shale just above pay sand of Curtis No. 1, Shreveport, La.	22.6
Reddish shale just above pay sand of Curtis No. 1	20.0
Sample of Shale from deep gas sand, Hodges' Ward No. 1, Shreveport, La	16.9

† A. F. Melcher, "Determination of Pore Space of Oil and Gas Sands," *Trans. Am. Inst. Min. Eng.*, Vol. 65 (1921), pp. 480–89.

C‡

Almost unconsolidated sand; depth, 3,965 ft.; Santa Fe Springs field, Cal	31.0
From thin stratum in Salinas shale of Monterey group; dip, 55° S.; Southwest of Goleta Landing, Santa Barbara County, Cal.	33.3

‡ A. F. Melcher, "Texture of Oil Sands with Relations to the Production of Oil," *Bulletin American Association Petroleum Geologists*, Vol. 8 (1924), pp. 758–59.

TABLE III—*Continued*

D§	
Delesse:	
Shale (one determination)	7.55
Slate (one determination)	.49
King:	
Clay (average of numerous tests)	45.00
Geikie:	
Clay (many tests)	53.00
U. S. Department of Agriculture:	
Soils (many tests)	55.00
E‖	
Surface material of hard smooth playa; Roger's Dry Lake, Lancaster, Cal	38.30 37.80
Pleistocene alluvium; Mojave River, Yermo, Cal. (very fine sand and some clay)	43.10
Pleistocene alluvium; 5 ft. below and separated from preceding by gravel layer	35.70
Glacial lake deposit; Pomperaug Valley, Conn	41.90
F¶	
Thirty-six samples from major stream valleys of San Diego County, Cal.:	
Coarse sand	39–41
Medium sand	41–48
Fine sand	44–49
Fine sandy loam	50–54
G**	
Semiliquid mud from the bottom of the Hudson, near Canal Street, New York City	77.15–88.40
Mud deposited on a crate suspended from Erie Railroad Pier No. 9, Jersey City	88.18
H††	
Hudson River silt at depth of 40 to 50 ft	55–65
I‡‡	
Water content of various recent mud deposits along the sea coast	40–90+

§ M. L. Fuller, "Amount of Free Water in the Earth's Crust," *U. S. Geol. Survey Water Supply Paper 160* (1906), p. 61.

‖ O. E. Meinzer, *op. cit.* According to E. W. Shaw, "much of the newly deposited material of the Mississippi River delta has a porosity of 80 to 90 per cent."

¶ A. J. Ellis and C. H. Lee, "Geology of the Ground Waters of the Western Part of San Diego County, California," *U. S. Geol. Survey Water Supply Paper 446* (1919), pp. 121–23.

** J. V. Lewis, *op. cit.*, p. 563.

†† B. H. M. Hewett and S. Johanneson, *Shields and Compressed Air Tunneling* (1922), p. 295.

‡‡ E. W. Shaw, *op. cit.*, p. 1451.

with paraffin of known density and weighing in air and in water. Correction was made for the temperature of the water in which the sample was immersed and for the moisture content of the specimen. The mineral density determination was made on the dried powder with a pycnometer equipped with thermometer and side stem. The contents of the pycnometers were heated to boiling to drive out air.

DISCUSSION OF POROSITY DATA

The miscellaneous data for outcrop samples of various shales and clays are of relatively little value in determining an exact relationship between pressure and porosity, as the effectiveness of the factors controlling porosity is often variable even over small areas. Furthermore, it is frequently impossible to make even roughly accurate calculations of the maximum amount of overburden to which a rock has been subjected during its history. These data, however, do make clear general relationships and furnish valuable evidence on certain points.

The series of determinations due to Sorby (Table III, A) and those made by the writer (Table I), when arranged in order of geologic age, agree in showing a distinct relation between age and porosity. The effect of time on the process of compaction has been previously discussed. It seems that once hydraulic equilibrium has been approximated within a sediment, further passage of time will result in but little additional shrinkage. It is apparent, however, that, in so far as the older sediments are apt to have been exposed to greater or more repeated compressive stresses than those of more recent periods, it is only reasonable to expect porosity to decrease with age. Thus, in the case of the rocks considered here, the decreased porosity of the older sediments may be explained either as a result of deeper burial or of more intense dynamic metamorphism.

Lee's determinations on the alluvium of San Diego County, California (Table III, F) illustrate the increase of porosity with fineness of grain. The high porosity of an almost unconsolidated sand at a depth of 3,965 feet in the Santa Fe Springs field, California, and the equally high figure for the thin stratum in the folded Salinas shale of Santa Barbara County (Table III, C), show the failure of even moderately high pressure to reduce the pore space of sand be-

yond a certain point. Data on the Alloway clay at Yorktown, New Jersey (Table I), from depths of 4, 11, and 13 feet, shows the effect of weathering in increasing porosity. The influence of weathering is also seen in the high porosity of Cherokee shale picked up on a mine dump near Fulton, Missouri (Table I), while the low porosity of a Permian shale from Salina, Kansas (Table I), is undoubtedly connected with its high percentage of lime carbonate. The figures on the water content of Hudson River silt at depths of 40 or 50 feet (Table III, H) are extremely interesting as showing that porosities of 50 per cent or more may be maintained in natural sediments even under the weight of considerable overburden. From the data in the preceding tables conclusions may also be drawn as to the mineral density of shale, the variation in rock density among sediments, and the gravity anomalies in areas of sedimentary rocks.

The data obtained from well cuttings afford the most interesting key to the relationship between pressure and porosity. Of the samples studied, those from the Ranson well of Hamilton County, Kansas (Table II), are most valuable, as they represent the longest vertical sequence and come from a region in which at least no proof of major lateral compression exists. The deepest sample obtained from the cuttings of this well comes from 5,440 feet below the surface and is probably of early Pennsylvanian age; at the top of the column is the Graneros shale of Upper Cretaceous age. The Greenhorn limestone, the Carlile shale, and the Niobrara formation are all present in Hamilton County above the Graneros shale, and of aggregate thickness equal to 1,000 feet, as estimated by Darton.[1] The Pierre shale, while absent in the county, is believed to have been removed by post-Cretaceous erosion, and the Fox Hills sandstone may also have originally covered this area. In the Nepesta quadrangle, a hundred miles farther west, the Pierre shale is 2,300 feet thick,[2] and in the Colorado Springs[3] and Castle Rock[4] quadrangles

[1] N. H. Darton, *U. S. Geol. Survey Geol. Atlas*, Syracuse-Lakin folio (No. 212, 1920), p. 2.

[2] C. A. Fisher, *U. S. Geol. Survey Geol. Atlas*, Nepesta folio (No. 135, 1906), p. 2.

[3] G. I. Finlay, *U. S. Geol. Survey Geol. Atlas*, Colorado Springs folio (No. 203, 1916), p. 8.

[4] G. B. Richardson, *U. S. Geol. Survey Geol. Atlas*, Castle Rock folio (No. 198, 1915), p. 6.

the combined thickness of Pierre and Fox Hills reaches 3,000 feet, while near Denver the Pierre alone has a reported thickness of 7,000 feet. In view of this information it seems reasonable to suppose that at least 2,500 feet of Cretaceous sediment once existed above the Graneros shale in Hamilton County. This would make the maximum depth of burial of the deepest shale cutting obtained from the Ranson well approximately 8,000 feet.

In the light of all available data on recent deposits and laboratory deposition, 50 per cent is considered a conservative estimate of the average initial porosity of a hundred feet of freshly deposited mud. At the other extreme, porosity may be reduced practically to zero, as shown by the determinations made on slates by Delesse and Sorby (Table III). The low porosity of these rocks is due to the enormous pressures exerted during periods of intense dynamic metamorphism. While it seems entirely possible that under sufficient load similar rocks could be produced by gravitational pressure alone, unqualified examples of such are lacking, although slates in the Greenville series and in the Shuswap terrane of British Columbia have been explained in this way.[1] The lowest known porosity which may be ascribed with any certainty to gravitational pressure is the 8.09 per cent porosity of the shale cuttings from the Ranson well at a depth of 5,437–40 feet, due to a total calculated overburden of 8,000 feet. The deepest cuttings from the Lynn well, Montgomery County, Kansas, show a porosity of slightly less than 8 per cent, but this well is located much nearer to areas of known crustal deformation, and the data thus seem less reliable.

Using the extremes of 50 per cent porosity as the average of an initial hundred feet, and 8 per cent as the figure at a depth of 8,000 feet, porosities corresponding to intermediate depths of burial were calculated from data on the Ranson well and other well cuttings and outcrop samples of non-calcareous, non-arenaceous shale. In this way an approximate porosity gradient was determined and plotted as curve A, Figure 3. Following Sorby's suggestion[2] that the relation of pressure to porosity may be inversely proportional to the ratio of pore space to solid particles, assuming an average porosity of 50 per cent for the first hundred feet and a porosity of 8 per cent at a depth

[1] C. K. Leith, *op. cit.*, pp. 129–30.

[2] H. C. Sorby, *op. cit.*, p. 230.

of 8,000 feet, and converting feet of sediment into pressure per unit area in such a way as to take into consideration the increase of density with depth, a second set of data was calculated. This plotted

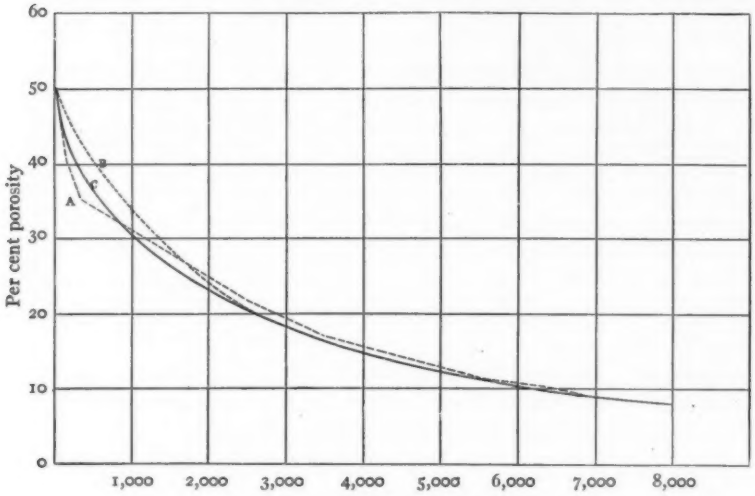

FIG. 3.—Feet of overburden

curve, B, shows striking similarity to curve A, especially where pressure is high, but fails to hold for low pressures and high porosities. A third and final curve, C, was drawn in which the irregularities of

TABLE IV

RELATION OF POROSITY OF SHALE TO OVERBURDEN

Feet of Overburden	Percentage of Porosity
Average porosity of initial 100 ft	50
1,000	30
2,000	23
3,000	18
4,000	14.7
5,000	12.2
6,000	10.4
7,000	9
8,000	8

curve A were adjusted so as to form a regular curve based on both A and B. The porosity gradient shown by curve C and Table IV is the one used in all subsequent calculations.

From the porosity gradient thus determined it is possible to calculate the approximate vertical shrinkage which a bed of mud or clay will undergo during compaction. For instance, a hundred feet of freshly deposited mud, when buried under 3,000 feet of sediment, will be reduced to about 60 feet. On the other hand, a shale with a porosity of 8 per cent must have had a thickness of about 180 feet when first deposited.

No attempt is made to claim mathematical accuracy for the porosity gradient previously given. A brief consideration of the material available for study, the factors controlling porosity, and the limitless variety in lithology and geologic considerations over the earth is sufficient to show that great exactitude is impossible as well as unnecessary where application is to be general rather than specific. It is thought, however, that the table may be approximately indicative of the true relation between porosity and pressure for the particular type of shale used, and roughly so for all dominantly argillaceous sediments. The testing in detail of the accuracy of the figures here presented must await the accumulation of further data.

INFLUENCE OF VERTICAL COMPACTION ON STRUCTURE

In a homogeneous series deposited on a horizontal surface the effect of gravitational compaction would be seen in an increase in rock density, a decrease in porosity, and a decrease in thickness, but the attitude of the bed as a whole would remain unchanged. When, however, deposition occurs on a surface of considerable relief, or the sediments vary laterally in character, the structure of the strata may be considerably affected by compaction, as has been pointed out by many writers. It is interesting to consider the structural changes produced by settling, in the light of the pressure-porosity relations shown by Figure 3.

For the sake of illustration assume a granite hill 100 feet high on an old erosion surface, covered by a shallow sea in which muds are now being deposited. In relatively shallow water, where wave action extends to the bottom, sediments will naturally tend to be shifted from the high areas to the hollows and low places of the sea floor during the development of a profile of equilibrium. Consequently mud deposits will be built up practically to the level of the hill top before deposition occurs there. Now, suppose a recognizable key

bed is laid down as soon as the mud deposit has reached the level of the summit of the hill. A cross-section will then show a 100-foot hill of relatively incompressible rock surrounded by a hundred feet of mud of an average porosity of 50 per cent, both covered by a horizontal key bed.

Now let deposition continue in the sea until a thousand feet of sediment rest upon the initial deposit. The mud surrounding the hill is now under a load of 1,000 feet of sediment, and under this pressure its original porosity of 50 per cent has been reduced to 30 per cent. The change from 50 per cent to 30 per cent pore space involves a decrease of 28.6 per cent in the volume of the sediment and, as this decrease is taken up in vertical shrinkage, the 100 feet of mud originally deposited is reduced to 71.4 feet. The granite hill, which is practically incompressible, has still remained 100 feet thick, and the key bed, which extended across the whole area, has everywhere been compressed equally. The result is that the part of the key bed resting on the summit of the hill is now 28.6 feet higher than that which rests on what originally constituted the 100 feet of mud deposit. In other words, contours drawn on the top of the key bed would now show a dome with 28.6 feet of closure over the top of the buried hill.

Suppose 2,000 feet of sediment had been deposited above the key bed. The porosity of the basal mud deposit would now be only 23 per cent; its thickness would be only 64.9 feet; and the closure in the key bed overlying the hill would be 35.1 feet. Similarly, the left-hand column of Table V (A) shows the amounts of closure produced in the key bed, with various amounts of overburden, up to a closure of 45.7 feet under 8,000 feet of overburden.

If deposition were equal over the whole area and the beds concerned were perfectly flexible under their own weight, the closure in a bed at any distance above the base would be the same as in the basal key bed. Obviously, however, the same principle which caused deposition around the bottom and flanks of the hill to precede that on the summit must be assumed to be active during the deposition of the whole series. In other words, wave action in a shallow sea depositing homogeneous material tends to maintain an almost level

profile of deposition for that material, and any depressions which develop are filled by a shifting of sediment from the surrounding higher areas. As deposition and settling over the buried hill are contemporaneous, more sediment must be deposited around the upward projection of the hill than in the area directly above it in order to maintain this level of deposition.

Again for purposes of illustration, consider the first thousand feet of sediment deposited above the key bed. The weight of this sediment has produced in the key bed a closure of 28.6 feet over the buried hill. However, at the depositional surface, 1,000 feet above the key bed, the closure is zero, as the overburden is zero and continuous sedimentation will have completely masked the effects of settling of the basal mud by additional deposition in the area surrounding the upward projection of the hill. In order to maintain this regular profile at the depositional surface the excess sediment in the area overlying that surrounding the hill must equal 28.6 feet, which is the amount that the basal hundred feet has shrunk. As this extra material may be assumed to have been added continuously during the deposition of the thousand feet of sediment in order to keep pace with settling, it may be considered, in order to simplify the calculation, to have an average porosity of 36 per cent, the mean of the porosities for overburdens of 50 and 1,000 feet, as shown in Figure 3. Thus, 28.6 feet, of average porosity 36 per cent, represent the excess of deposition about the sides of the hill during a total deposition of 1,000 feet. This may be called Stage 1.

Stage 2.—The thickness of sediments above the key bed is now 2,000 feet. The porosity of the basal 100 feet is 23 per cent, and the closure in the key bed is 35.1 feet.

The 28.6 feet of extra material, with a porosity of 36 per cent, added during Stage 1, have now been reduced to an average porosity of 26 per cent (Fig. 3), and a consequent thickness of 24.7 feet. This fails to compensate for 35.1 feet of closure at the base, and consequently the structure, at a height of 1,000 feet above the key bed, will show a closure of 35.1 minus 24.7, or 10.4 feet.

The closure at the depositional surface, now 2,000 feet above the key bed, is still zero, and in order to have maintained the regular

surface profile, 10.4 feet of sediment of average porosity, 36 per cent, must have been added in the top thousand feet in the area around the upward projection of the hill.

Stage 3.—The thickness of sediments above the key bed is now 3,000 feet. The closure in the key bed is now 39.1 feet.

The 28.6 feet of extra material, with average porosity of 36 per cent, added during the deposition of the first thousand feet above the key bed has now been reduced to an average porosity of 20.3 per cent and a consequent thickness of only 22.9 feet. This fails to compensate for 39.1 feet of closure in the basal key bed, and consequently the structure, at a height of 1,000 feet, now shows a closure of 39.1 minus 22.9, or 16.2 feet.

The 10.4 feet of extra material, with porosity of 36 per cent, added between 1,000 and 2,000 feet above the key bed, has now been reduced to a porosity of 26 per cent and a thickness of 8.9 feet. This fails to compensate for the 16.2 feet of closure 1,000 feet above the key bed, and hence the closure at a height of 2,000 feet will be 16.2 minus 8.9, or 7.3 feet.

The closure at the depositional surface, 3,000 feet above the base, is still zero, as 7.3 feet of extra material with an average porosity of 36 per cent have been added around the upward projection of the hill during the deposition of the uppermost 1,000 feet.

In a similar manner the amount of closure and upward projection of structure may be calculated for thicknesses of sediment up to 8,000 feet. Table V shows the results of such calculations, for a 100-foot hill, in convenient tabular form. It is important to remember that the detailed accuracy of this table depends on the assumption that the basal sediment and the extra sediment added around the upward projection of the hill are muds. In a stratigraphic series where other types of sediments are important the figures of the table must be reduced or increased accordingly. Table V is constructed for use with a 100-foot hill, but for points 1,000 feet or more above the base the error is not greatly increased, in the case of smaller or larger basal eminences, by simply multiplying the figures by the appropriate fraction or multiple of 100. Thus, for example, a structure with a closure of 50 feet, exposed by the erosion of a 7,000-foot series down to a thickness of 3,000 feet, would indicate a buried hill about

400 feet high. Table VI shows closures calculated for a hill 500 feet high.

The structure of overlying beds is also affected by settling over bodies of sand, deposited as bars, channel fillings, and the like in strata which consist essentially of muds or clays. The column of mud occupying the same horizon as the sand body is so much more

TABLE V

CLOSURE DUE TO SETTLING OF MUD OR SHALE OVER HILL 100 FEET HIGH

THICKNESS OF SHALE (IN FEET)	HEIGHT ABOVE BASE (IN FEET)								
	Base	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000
0	0								
1,000	28.6	0							
2,000	35.1	10.4	0						
3,000	39.1	16.2	7.3	0					
4,000	41.4	19.5	11.2	4.9	0				
5,000	43.1	22.0	14.1	8.3	3.8	0			
6,000	44.2	23.6	16.0	10.4	6.5	3.0	0		
7,000	45.1	24.9	17.5	12.1	8.4	5.1	2.5	0	
8,000	45.7	25.7	18.5	13.2	9.6	6.5	4.1	2.8	0

TABLE VI

CLOSURE DUE TO SETTLING OF MUD OR SHALE OVER HILL 500 FEET HIGH

THICKNESS OF SHALE (IN FEET)	HEIGHT ABOVE BASE (IN FEET)							
	Base	1,000	2,000	3,000	4,000	5,000	6,000	7,000
0	0							
1,000	90	0						
2,000	124	46	0					
3,000	145	73	33	0				
4,000	157	88	51	23	0			
5,000	166	100	65	39	19	0		
6,000	173	108	74	49	31	15	0	
7,000	178	114	81	57	40	25	12	0

compressible than the sand that overlying strata are bent over the sand during settling, in the same way that they are domed over a buried hill. In calculation of the structure produced in such cases it is necessary to consider that sand may compact as much as 5 or 10 per cent during the early stages of consolidation, depending on its lithologic character and the rapidity with which the grains become cemented by infiltration. Deposition of a thick basal sand stratum may prevent the development of pronounced structures, even above

a surface of considerable relief, if the thickness of the sand is nearly as great as the relief of the old erosion surface.

CHARACTER OF STRUCTURES PRODUCED BY VERTICAL COMPACTION

As the structure produced by the settling of sediments over buried topography is a reflection of that topography, the nature of the structures will depend on the character of the old erosion surface on which deposition takes place. An interesting interpretation of the character of the folds to be expected from settling over different types of topography is contained in Rubey's discussion of the origin of the folds of Russell County, Kansas.[1]

The effect of unconformities, in the stratigraphic column above the base, on the upward reflection of structure becomes a point of great importance in determining what erosion surface is responsible for folds now appearing at the surface. This information is particularly valuable in untried territory where there is doubt as to whether folding extends down to oil-bearing strata, or is limited to a more recent period of sedimentation.

As time unaccompanied by pressure probably has but little influence in changing porosity after approximate hydraulic equilibrium has been approached, the time value of an unconformity is of small importance except as it determines the amount of erosion taking place. Hence unconformities in the stratigraphic column will have little effect on the normal upward gradient of porosities except when a greater amount of overburden is removed during the erosion period than is subsequently despoited, in which case a marked increase in porosity will be noticed in passing upward across the surface of unconformity.

Although the porosity gradient may or may not be changed by an unconformity, the upward reflection of structure will always be diminished. If the amount of material removed by erosion is greater than that subsequently deposited, the upward reflection will cease at the surface of unconformity. If the weight of subsequent deposition is greater than that of the strata removed, there will be still a decrease in closure at the unconformity, and change in closure

[1] W. W. Rubey and N. W. Bass, "The Geology of Russell County, Kansas," *Kansas State Geol. Survey Bulletin 10* (1925), Part I, pp. 72–86.

above this will theoretically be negligible until a thickness of overburden equal to that which previously existed is attained, when the upward decrease in closure will be resumed.

If the surface of unconformity between the basal buried topography and the present surface is one of considerable relief, it may be that upward reflection of structures in the lower series will be completely obscured in the upper series by counteracting eminences on the second erosion surface.

Increase of dip with depth, the thinning of shales over the high points of structure, the gentleness of folding, the abundance of round or elliptical structures, and general lack of system have been mentioned by Blackwelder[1] and Powers[2] as characteristics of folds attributed to the compaction of sediments. It should be noted, however, that in all folding of the parallel or concentric type, dips must decrease away from the concentrum, and an increase of folding with depth does by no means necessarily imply an origin due to settling. It may be the result of simple concentric folding due to lateral forces, or it may be due to gradual or intermittent uplift contemporaneous with deposition. Thinning of all strata over the buried hill should be especially evident near the base of the series, and the decrease in importance of this feature should be coincident with the upward decrease of closure. The thinning may be due both to less original deposition directly above the summit of the hill and to a slight stretching of strata over the crest of the fold. The shifting of material by wave action during deposition from directly above the hill to the surrounding areas, in order to compensate for the greater settling which occurs there, may lead to some concentration of sand or coarse material in the column directly above the hill.

In considering the gentleness of folding it must be borne in mind that the burial of high isolated mountains under sedimentary strata is not a common geologic phenomenon. Moreover, the sharpness of relief of subaerial erosion surfaces must be greatly diminished by wave erosion and the deposition of coarse, relatively incompressible

[1] Eliot Blackwelder, "The Origin of Central Kansas Oil Domes," *Bulletin American Association Petroleum Geologists*, Vol. 4 (1920), pp. 93–94.

[2] Sidney Powers, "Reflected Buried Hills and Their Importance in Petroleum Geology," *Economic Geology*, Vol. 17 (1922), p. 256.

sediments about the flanks of hills before the land is completely covered by the advancing sea. Finally, even when a steep hill does become buried under relatively compressible sediments, the folding due to compaction must, by its nature, diminish rapidly upward both in closure and in steepness of dip. It thus seems that, while low ill-defined folds of gentle dip may frequently be due to settling, it must be rarely and only under special conditions that large, well-defined, surface structures may be attributed solely to compaction over topographic features separated from them by thousands of feet of rock.

A rather disconcerting characteristic of structures which otherwise seem best explained by the theory of differential settling is the frequency with which surface structure fails in being exactly superimposed over the structure of lower strata. This situation prevails in the Pershing and many other Osage structures. No attempt will be made here to give explanations of this lack of superimposition for specific cases, as this would require detailed study of the fields in question; however, a few factors which may possibly have exerted influence in certain cases may be suggested.

1. Regional tilting subsequent to compaction will shift the structure in higher beds down the dip relative to its position in lower beds.

2. The settling of sediments over an originally asymmetrical hill will cause a shifting of the axis of folding toward the steeper flank in successively higher beds, as in the case of any other asymmetrical fold. Difference in the character of material deposited on different sides of a symmetrical basal hill may cause it to be reflected asymmetrically.

3. Converging sand bodies between the buried hill and the present surface may produce a shifting of the apex of structure in higher beds.

4. Irregular surfaces of unconformity between the base and the top of the series may cause considerable alteration in the position and form of the structure in overlying beds. Inclined plane surfaces of unconformity will cause the apex of structure in higher beds to shift in the direction of inclination.

APPLICATION OF QUANTITATIVE DATA

Without detailed information about structure, character, and variation of sediments, and a general idea of the regional geologic history it is, of course, impossible to test definitely the adequacy of the compaction of sediments as a source of folding in any specific area; however, two cases will be considered which may suggest the value of applying quantitative data to other areas.

The following instance is cited by M. J. Mehl[1] as evidence of the importance of the effects of compaction on the structure of sedimentary strata:

> In the southwestern part of Woodson County, Kansas, a well was drilled under his [the author's] direction. Cuttings from each screw were obtained either by the writer or his associate, Mr. George Baldridge. At regular intervals the depth was checked by steel tape measurements. The samples were studied with considerable care and it is thought that the resulting log is somewhat above the average in dependability. This log was compared with the log compiled from many wells of the surrounding region, and it was found that the first log agreed in all essentials with the composite log save for the 90 feet immediately above a recognizable horizon in the Mississippi lime. This horizon formed an essential plane over the entire region. Where the well was drilled from which the first log was taken, the Mississippi lime extended 90 feet above this plane. In all of the wells grouped about the first on three sides the reference plane was at the top of the lime. It is evident that there was a limestone hill 90 feet high at the point where the first well was drilled. It is also evident that the only deformation of the region must have come from the compression of the 90 feet of shale found above the reference plane in the surrounding wells and lacking in the central test, for the reference plane was undistorted and the sections from the various wells agree perfectly upward from a point 90 feet above the reference plane. The central well was drilled near the center of a domelike structure with 30 feet of inclosure. The compression of the lower shale to 90 feet, then, produced a bulge of 30 feet over the non-compressible limestone hill.

In this part of Woodson County the depth to the Mississippian limestone is approximately 1,300 feet. The lower half of the sedimentary column, belonging to the Cherokee and Marmaton formations, is almost entirely shale, and shale constitutes some 70 per cent of the whole thickness of sediments. The maximum overburden in

[1] M. J. Mehl, "The Influence of the Differential Compression of Sediments on the Attitude of Bedded Rocks," unpublished manuscript. Quotation with permission of author.

this area, as shown by porosity data in neighboring counties and as deduced from other considerations, may be estimated as of the order of five or six thousand feet. The height of the hill is placed at 90 feet. Referring to Table V, we find, for a thickness of 6,000 feet of sediment over a hill 90 feet high, a closure of about 20 feet, 1,300 feet above the base.

As the closure mapped at the surface was 30 feet, it is apparent that in this case the table errs on the side of conservatism, if it is assumed that the 90 feet shown by the one well is the maximum elevation of the hill. The discrepancy is easily explained, however, when the character of the Cherokee shale in this area is considered. Much of the basal Cherokee in this region is a black shale with frequent lenses of coal, grading into carbonaceous shales. It is evident that the shrinkage of such strata, due to the combined effects of decomposition and gravitational compaction, should be considerably greater than the vertical shortening induced by pressure on a more purely argillaceous deposit. In fact, the thick stratum of Cherokee shale, except for the presence of sand lenses and occasional local unconformities, constitutes an ideal medium for the upward reflection of topography, and it seems that wherever it is developed, in its typical eastern Kansas and Missouri form, the figures of the first three columns of the table may well be increased possibly by 50, 30, and 20 per cent, respectively.

The conditions of Cretaceous deposition in western Kansas were less favorable to upward reflection of topography. In the south the thick Cheyenne sandstone is the basal deposit; initial Comanchean deposition in the west, according to Twenhofel's correlations,[1] was less uniform, and the rather frequent lateral variation from sand to shaly strata must certainly be reflected in the higher beds. In west-central Kansas the shale frequently found at the base of the Comanchean may have allowed upward reflection of post-Permian topography to a degree sufficient to cause appreciable modification in the structure of beds now exposed at the surface. Folding of this sort, and that due to settling over sand bodies in the Cretaceous strata,

[1] W. H. Twenhofel and W. L. Stryker, "The Subsurface Distribution of the Comanchean in Western Kansas," *Bulletin American Association Petroleum Geologists*, Vol. 9 (1925), pp. 1105–14.

are believed by Twenhofel[1] to be the source of his "amoeboid" structures, and Rubey[2] considers this at least a partial explanation of the "gentle unsystematic folds" of Russell County.

Eight well logs from Russell and Lincoln counties show an average of only 66 per cent shale in the basal 100 feet of Cretaceous deposit; hence it seems probable that the figures of Table V should be reduced somewhat in considering reflection through these strata. Porosity determinations on well cuttings and surface samples from Russell County and neighboring areas, as well as other lines of evidence, seem to indicate that the total Cretaceous overburden, deposited on the post-Permian erosion surface here, was no more than two or three thousand feet. Considering the depth of burial, the distance to the present erosion surface, and the character of the sediments involved, it seems probable that irregularities due to post-Permian erosion would appear reflected at the present surface reduced to only about a fifth of their original magnitude. Sandstone lenses and channel fillings, such as are typical of the Cretaceous strata here, must have produced marked effects on surface structure.

The prominent northward-trending anticlines in the Cretaceous of the Russell County region, such as the Fairport-Natoma anticline with a horizontal extent of more than 20 miles and a relief of 100 feet, call for a different explanation, according to Rubey.[3] Wells drilled in western Russell County seem to indicate that the Fairport-Natoma structure continues downward with increasing intensity of folding to the pre-Pennsylvanian rocks, and its size, form, and relations to other structures lead him to conclude that it may probably have originated as a result of the settling of sediments over a somewhat dissected fault scarp in the basal pre-Pennsylvanian rocks.

The post-Mississippian erosion surface is 3,000 feet below the post-Permian surface. Assuming that some 2,000 feet of strata were removed during post-Permian erosion, a maximum pre-Cretaceous thickness of 5,000 feet is allowed above the Mississippian and Ordo-

[1] W. H. Twenhofel, "Significance of Some of the Surface Structures of Central and Western Kansas," *Bulletin American Association Petroleum Geologists*, Vol. 9 (1925), p. 1063.

[2] W. W. Rubey and N. W. Bass, "The Geology of Russell County, Kansas," *Kansas State Geol. Survey Bulletin 10* (1925), Part I, p. 80.

[3] W. W. Rubey and N. W. Bass, *op. cit.*, p. 81.

vician rocks. In a shale series, such as that on which Table V is based, the reflected structure at the height of 3,000 feet above the base would show less than a tenth of the original magnitude. The log of the Phillips well, a few miles east of the Fairport-Natoma anticline, with correlations by Bramlette,[1] shows that the basal 500 feet of Pennsylvanian strata in this area carry less than 30 per cent shale; moreover, less than half of the overlying Pennsylvanian and Permian sediment is shale in the ordinary sense of the word. Hence the lithologic character of the sediments seems to call for a reduction of the figures of the table by certainly not less than 25 per cent. Now the structural relief of the Fairport-Natoma anticline is placed by Rubey and Bass at 100 feet, but topographic relief, even of the extravagant order of 1,000 feet on the post-Mississippian erosion surface, would still be inadequate to produce a closure of 75 feet in the rocks exposed at the post-Permian erosion surface, using the figures of Table V reduced by 25 per cent. During the long period of time marked by the absence of Triassic and Jurassic sediments, the underlying strata must certainly have reached equilibrium with their load of overburden, and the erosion of these periods cannot be assumed to have left any trace of reflected folding in the topography which was developed. It also is logical to conclude that until a weight of Cretaceous sediment, equal to the weight of older rocks removed, was added, there would be no further settling of the mass about any hypothetical pre-Pennsylvanian hills. There is no proof that Cretaceous sedimentation in this area ever exceeded the thickness of Permian strata removed by erosion, but even supposing that it did, further settling in the basal Pennsylvanian strata, induced by the addition of an extra one or two thousand feet of sediment, would be slight, and structure formed from this cause in Cretaceous rocks would be entirely negligible. In view of the foregoing considerations it seems highly improbable that major structural features in the Cretaceous rocks of this area can be safely attributed solely to settling over topography developed on the post-Mississippian erosion surface.

Similarly, for western Kansas in general, the long period of

[1] M. N. Bramlette, "A Subsurface Correlation of the Stratigraphic Units from Russell County to Marion County, Kansas," *Kansas State Geol. Survey Bulletin 10* (1925), Part II, Plate VI.

erosion following the deposition of the thick Pennsylvanian-Permian series must have left a topography showing little or no definite relation to the necessarily gentle folds resulting from reflection of irregularities on the post-Mississippian erosion surface. Subsequent Cretaceous deposition could have produced but little further shrinkage of the already fairly well compacted sediments, and hence almost all traces of faulting or folding of pre-Cretaceous age must be limited to the rocks below the Permian-Cretaceous contact. Certainly further settling over buried hills or mountains on the post-Mississippian erosion surface is not adequate to explain structures of any considerable magnitude in the Cretaceous rocks now exposed at the surface. Folds and faults in these strata must be due either to the effects of differential compaction of Cretaceous sediments and settling over irregularities on the post-Permian erosion surface, or to earth movements of Cretaceous or later time. Rubey has suggested the relation of the structures of the Russell County region to buried tectonic lines, and, although settling over an eroded fault scarp is by itself inadequate to explain surface structure, slight gradual or recurrent vertical movements along these lines, extending at least into late Mesozoic time, may account for the continuation of deformation downward through the older rocks with increasing intensity.[1]

POROSITY AS AN INDEX OF PRESSURE METAMORPHISM

The close relation between porosity and pressure in clays, muds, shales, and slates seems to have been amply proved by experimental compression of muds, by the regular decrease in porosity of sedimentary strata with depth, and by the association of the densest of argillaceous sediments with the regions of most intense metamorphism. From analytical data a rough scale of the relations between pressure and porosity for pressures up to that produced by 8,000 feet of rock overburden has been computed. The scale thus determined extends only to pressures of eight or nine thousand pounds per square inch, but a graphical representation of this scale seems to show rather conclusively that pressure necessary to cause

[1] The rejuvenation of buried topography and buried structure by earth movements has been discussed very recently by Sidney Powers, "Reflected Buried Hills in the Oil Fields of Persia, Egypt, and Mexico," *Bulletin American Association Petroleum Geologists*, Vol. 10 (1926), pp. 422–42.

further reduction of pore space increases approximately in proportion as the ratio of pore space to solid particles in the rock diminishes. Porosity thus becomes a fairly reliable index of the pressure which rocks of this nature have endured. The sensitiveness of the index decreases as porosities become lower, but variations due to lithologic character also become less important; on the other hand, when porosity is high it is a very sensitive index of pressure, but slight variations in the character of the sediment are accordingly magnified.

The application of data on the relation between pressure and porosity has been made in connection with a consideration of the structural effects of gravitational compression. However, the relation may be also of importance in other fields of investigation. For instance, porosity may frequently be of value in determining the paleogeography of regions of little crustal disturbance, as the porosity of surface rocks may to a considerable extent be indicative of the thickness of sediment which once existed above them.

If the porosity of a fine-grained rock is an index of the pressure to which it has been submitted, it must also be an index of the pressure which the rock has transmitted. The lateral pressure necessary to fold and crumple strata must be far greater than the pressure upon them due to the weight of overlying rock. Hence, in the case of isolated folds in a region which has suffered little diastrophism, the porosity of the fine-grained argillaceous sediments should be a valuable check on the plausibility of ascribing folding to the lateral transmission of stress through these sediments from some distant center of disturbance. Similarly, around regions of great deformation, the porosities of argillaceous strata may furnish evidence as to the size of the area influenced by the lateral forces developed during the disturbance.

Carbon ratios in coal have been used successfully as an indication of the probability of the existence of oil, high carbon ratios being a criterion of intense pressure metamorphism. May not the porosities of shales be of similar value? Argillaceous rocks are the most widespread of all sedimentary types, and it is hoped that these suggestions may lead to the accumulation of more data on the porosities of muds, clays, shales, and slates, and the consequent testing of the hypotheses here advanced.

OIL PROSPECTS IN NORTHEASTERN CHINA[1]

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ABSTRACT

By far the greatest part of northeast China consists of rocks of types and ages in which there is no possibility of oil. Some areas, however, deserve consideration. Among these the most important is the Shensi basin, situated in northern Shensi Province overlapping into extreme western Shansi, eastern Kansu, and a bit of southern Inner Mongolia. Shensi basin was studied in reconnaissance and local detail by the writers and assistants. Two brief papers have appeared on the subject, but the following is the first authentic account of the oil geology of this area specifically, and of northeast China in general. This basin appears to have some chance for oil production on a small scale, but there is unlikely to be intensive oil development in it. The rocks are in general too sandy throughout great vertical thicknesses, the marginal areas are too highly folded and perhaps too greatly metamorphosed, whereas the central areas are mainly monoclinal and so flat-dipping as not to permit accumulations in quantity.

INTRODUCTION

Preliminary statement.—Northeastern China[4] may be defined, for the purposes of this paper, as that part of China proper lying south of Mongolia, east of Tibet and Sinkiang, and north of the provinces of Honan and Shantung.

References to known or reported occurrences of petroleum in northeastern China have appeared from time to time in books of travel and in general treatises on oil, but most of these have been indefinite as to location, deficient in descriptions, or lacking in statements as to the geological relations of the seepages.

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[4] Properly written, each syllable of Chinese place names should be separate, since each represents a different word with its own idiographic character. It is, however, the common practice of English writers to unite the parts to form continuous words. It should be noticed that the termination *hsien*, *pu*, *fu*, and *chou* or *chow* indicate cities of varying political rank. They are not an essential part of the designation and their use, or omission, does not affect the significance or identification of the name. We have followed the practice of Willis and Blackwelder in separating the component parts of formation names by hyphens.

In 1913–15, the writers and associates had the opportuntity, in connection with explorations for American clients[1] working in conjunction with the Chinese government, of making many geological cross-sections in western Shansi, northern Shensi, and eastern Kansu, the most promising portion of northern China from the standpoint of possible profitable production of petroleum, as well as in less likely territory of northern Chihli. So far as known to them, they were the first geologists to visit and explore the first three of these regions.

Besides the geological examinations and the investigations of new oil seepages encountered in the field by the six parties working under the writers' direction, every attempt was made to verify all seepages mentioned in literature as occurring in the area explored, as well as a large number reported to the Chinese National Oil Administration.

The explorations mentioned definitely established the limits of the possible oil-bearing formations and their character and structure within the North Shensi basin, and threw much new light on the probability of future production.

For some years this information was, for business reasons, held as confidential, but permission to publish was later granted. Although two brief papers touching on oil have appeared,[2] no opportunity has until now presented itself for the preparation of any detailed account of the results of the explorations. Owing to the world-war and other causes affecting industrial progress in general, there has been little or no subsequent search for, or development of, petroleum in China, the conditions remaining practically as at the close of the writers' investigations in 1915,[3] except for the determination of the ages of certain formations by the Geological Survey of China mentioned hereafter.

[1] The name is omitted in this and other papers at the request of the clients themselves.

[2] Myron L. Fuller, "Explorations in China," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 3 (1919), pp. 99–116. Frederick G. Clapp, Discussion of "Petroleum Resources of China and Siberia," by Eliot Blackwelder, *Trans. Amer. Inst. Min. and Metal. Engrs.*, Vol. 68 (1923), pp. 1109–11.

[3] Relative to oil: Blackwelder's paper, quoted in preceding footnote, so far as it applies to the area here under discussion, is of general character and represents the knowledge available before the writers' investigations.

Area covered by explorations.—The outline map (Fig. 1) shows the principal routes of the writers and their associates. In all, something like 20,000 miles of geological traverse were run by the six parties in the field, of which nearly half was by the present writers.

Along these lines of traverse, the geology was mapped, sections made, and rough records of the topography kept. Where the routes were near enough to permit correlations from one to another, as in the Shensi basin, geological maps were prepared.

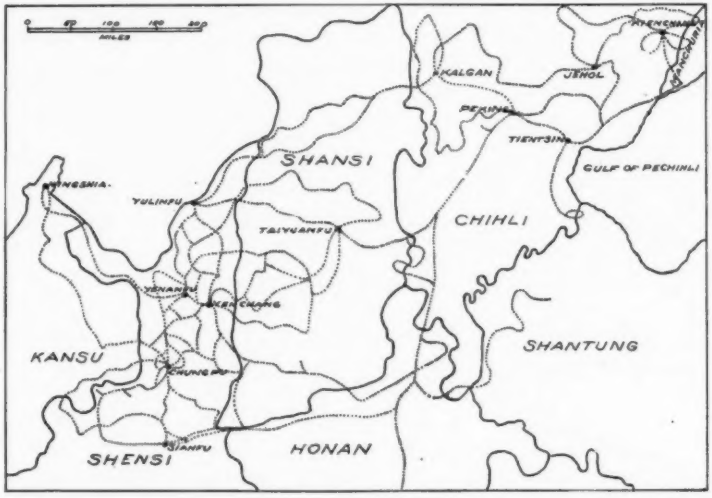

FIG. 1.—Route map, showing principal traverses of geological parties (traverses shown by dotted lines).

Field methods.—The short time available under the time limits of the concession necessitated the development of a method of mapping which should be at once accurate and rapid. The lines of traverse were run by compass, profiles determined by aneroid barometer, and the geology mapped directly from horseback, or, in case of one desert party, from camels. The method, which has been described in detail in *Economic Geology*,[1] proved substantially accurate in spite of its rapidity, the errors being negligible on maps of reconnaissance scale. In addition, many special areas were surveyed topographically and

[1] Myron L. Fuller, *Economic Geology*, Vol. 14, No. 5 (Aug., 1919), pp. 411–23.

geographically in detail by plane-table, and nearly 400 miles of stadia-levels run to connect map units and special geological structures.

Age-determinations.—It is unfortunate that there were no paleontologists connected with the explorations, and while some fossils were collected and sent to America for identification, no report upon them was ever received. The ages assigned in the field were tentative only. Some five years after the completion of our work, the newly organized Geological Survey of China sent parties into the region and collected sufficient plant and fish remains to establish the age of the greater part of what had been regarded as late Carboniferous (Permian) as Triassic and Jurassic.[1]

Acknowledgments.—The present paper is based on the personal work of the writers and upon reports, notes, and field maps of their associates in the explorations, including the late V. H. Barnett, Frank A. Herald, Edward L. Estabrook, Ernest Marquardt, and John M. Lovejoy. Credit for the discovery and description of certain seepages is due to topographers L. E. Gale and A. D. Hill. The writers are indebted to the reports of members of the China Geological Survey for age-determinations of formations above the Carboniferous as indicated in a preceding footnote.

GEOLOGY

Geologic provinces.—As has been pointed out in another paper,[2] the general geographic and geologic conditions in northeastern China are rather similar to those in eastern and central United States. In northeastern China proper and in Manchuria and Mongolia, are found sharply folded formations similar to those of New York and New England, and involving Jurassic, Carboniferous, and older rocks (Fig. 2). On the east is a coastal plain comparable to that of the United States except that the deposits, instead of resting on a smooth peneplain, lie on a surface characterized by sharp

[1] E. Norin, "Late Paleozoic and Early Mesozoic Sediments of Central Shansi," *Bull. Geol. Survey of China*, No. 4 (Oct., 1922), pp. 3–80.

C. C. Wang, "Stratigraphy of North Shensi," *Bull. Geol. Society of China*, Vol. 4, Pt. 1 (1925), pp. 57–67.

T. O. Chu, "Oil Fields of China," etc., *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), pp. 1295–98.

[2] Myron L. Fuller, "Explorations in China," *op. cit.*

monadnocks which project through the surface sediments and form "islands" rising above the plain. West of the coastal plain, with a narrow piedmont belt sometimes intervening, as in north Chihli, is a range of mountains with granitic cores analogous to the Blue Ridge of the Eastern United States, followed, beyond a basin 25–50 miles in breadth, by other sharply folded ranges, likewise with granitic cores, in a position corresponding to that of the Alleghenies.

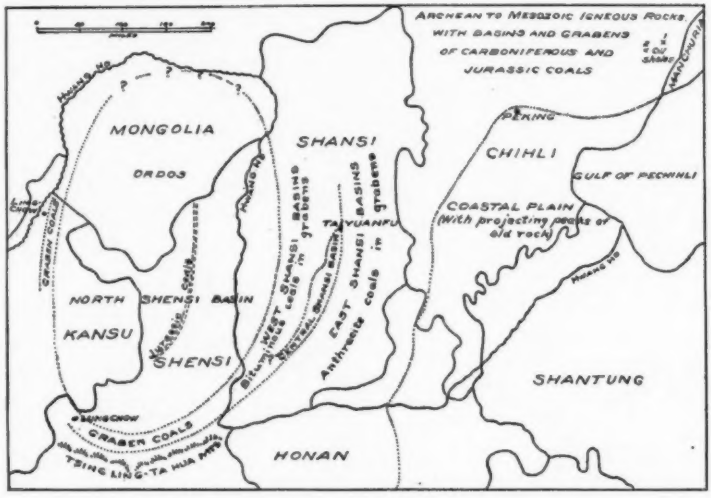

FIG. 2.—Map showing location of principal geological provinces discussed

Westward, the folds flatten into a broad basin, not unlike that of the Ohio-Mississippi Valley, extending beneath Shensi into Kansu, beyond which mountains reappear in discontinuous ranges in a position similar to that of the Rockies. The drainage of the basin escapes by the Hwang Ho from the southeast instead of from the south as in the United States, but the chief superficial dissimilarity is the presence of the great loess sheet which, except where it is cut through by streams, covers the underlying rocks with a mantle of fine yellowish silt from 500 to 2,000 feet thick.

Distribution of mountain ranges.—The general position of the more important mountain ranges of northern China and the simi-

larity of their arrangements to those of the United States has already been indicated. The best description is by Willis, who shows that the trend of the principal systems (Wu-t'ai Shan and others) of northeastern China is northeasterly, those south of central Shensi in central China (Ts'in-ling Shan and others) approximately east and west, those in northwestern China (Nan Shan and Kuan-Lung ranges of Richthofen) southwesterly, and those of central Mongolia roughly east and west.

STRATIGRAPHY

It will be sufficient in the present paper to give the comparative columnar sections for Chihli, Shansi, and Shensi, and eastern Sxechuan, the latter being after Blackwelder.[1] Only the most characteristic formations are included, but further details of the petroliferous series will be found in the discussions of the different provinces.

OIL PROSPECTS IN CHIHLI

INTRODUCTION

Rumors of showings of petroleum in Chihli have been prevalent among the Chinese for a long time, the reports coming from localities many hundreds of miles apart. So specific and definite were certain of the accounts that, in spite of general unfavorable geologic conditions, an examination was deemed desirable by the writers' employers, and several months were accordingly spent in an exploration of the province. The routes covered are indicated on Figure 1.

FORMATIONS AND STRUCTURE

North Chihli.—This is a complexly folded and faulted mountainous region with the Carboniferous, Jurassic, or younger rocks occupying a multitude of synclinorial basins, usually only a few miles in diameter, between Cambro-Ordovician or more ancient rocks, commonly upturned at high angles or separated from the basin areas by great faults. The dips within the basins are in few places less than 10 degrees and are commonly 30 to 45 degrees, or more. The folding and faulting has been accompanied by great intrusions and extrusions of igneous rocks, including granites, porphyries, melaphyres, diabases, and basalts, some of which are as

[1] *Researches in China: Stratigraphy of the Middle Yang-tzi Province*, Vol. i, p. 294.

TABLE I

Comparative Geological Columns

	Eastern Sze-chuan (Blackwelder)	Feet	Shan-si and Shen-si (Fuller and Clapp)	Feet	Chih-li (Clapp)	Feet
Recent			Alluvium, dunes, desert-wash, and modern loess (Unconformity)		Alluvium, desert-wash, and late coastal plain deposits (Unconformity)	
Pleistocene			Main body of loess (Unconformity)	1,500	Main coastal plain deposits (Unconformity)	
Tertiary			Sub-loess gravels and basal sandy loess (Unconformity)	500	Gravels and late basalts(?) (Unconformity)	500
Cretaceous			Older sub-loess gravels, sands, and clays (Peneplanation)	1,000 +	Not identified but probably present (Peneplanation)	
Jurassic			Gypsiferous beds Hwan-ho red to green shales and sandstones Hwa-cha regularly-bedded red sandstones Lo-ho massive, false-bedded red sandstone An-ting limestone in north I-chun conglomerate in south (Unconformity) Shen-si greenish and massive sandstones, coals, and thin shales	 3,000 1,000 2,000 200 500 6,000	Coarse conglomerates of tillite aspect in places Tuffs, shales, sandstones, and agglomerates with many interbedded and intrusive basalts, melaphyres and granites	4,000 4,000
Mesozoic	Kui-chou sandstones, red shales, and thin limestones	1,600	Pu-hsien red shale and sandstone (Permo-Triassic)	2,000	Red and green shales, sandstones and conglomerate, with coals	3,000
Permian			Shan-si coal measures (Permo-Carboniferous)	1,000		
Upper Carboniferous	Wu-shan limestone	4,000				
Lower Carboniferous Devonian, and Silurian	Sin-tan green to black shale with thin limestones	1,800	(Unconformity)		(Unconformity)	
Cambro-Ordovician	Ki-sin-ling limestone Nan-tou tillite with basal arkose (Unconformity)	5,000 500	Ki-chou limestone Man-to red shale and Tung-chuan quartzite (Unconformity)	5,000 500–1,000	Ki-chou limestone Man-to red shale, quartzite and sandstone (Unconformity)	4,000 1,500
Algonkian	Gneisses		Schists, thin limestones, and quartzites (Unconformity)		Schists, thin limestones, and quartzites (Unconformity)	
Archean			Granites, gneisses, and schists		Granites, gneisses, and schists	

late as Mesozoic or Cenozoic in age. Besides thick coal beds occurring in normal stratigraphic relationships, one pocket of sufficient thickness to warrant mining for local purposes was seen, without fireclay or associated sediments, lying between two melaphyre flows.

Coastal plain.—The coastal plain, lying mainly south and east of a line drawn from the Gulf of Pechihli to Peking, thence southward parallel with, and west of, the Peking-Hankow railroad, consists superficially of Quaternary silts made up largely of water-born and redeposited loess, with some local sands. Beneath the surface deposits, and occasionally projecting through and rising above them, are remnants of older formations, ranging in age from Archean through Algonkian, Cambro-Ordovician, Carboniferous, Permo-Mesozoic, Jurassic, and Tertiary, as well as volcanic or intrusive rocks possibly of even later date. Carboniferous and Jurassic basins, presumably of the northern Chihli type, undoubtedly exist, and there is a possibility of Tertiary deposits below the surface of the coastal plain, although no definite data are available as to their extent or structure. The Cretaceous was a period of peneplanation, and deposits in this age are presumably rare or lacking beneath the coastal plain.

METAMORPHISM

North Chihli.—The stage of metamorphism differs greatly in different localities, and is best indicated by the carbon ratios, or percentages of fixed carbon in pure coals (ash and water eliminated). Although the ratios vary with proximity to zones of especially marked disturbance and more particularly to igneous intrusions, the carbon ratio is in very few places less than 66, while in places coals have been locally converted almost to graphite. The Kaiping field 100 miles east of Peking, the principal coal center of Chihli, shows a ratio of about 76, but in the Manchurian fields to the east the ratio is as high as 87 in the Carboniferous coals and as low as 66 in the Jurassic coals.[1]

Coastal plain.—The carbon ratios of the Carboniferous and Jurassic rocks beneath the surface formations are assumed to be essentially the same as in the basins of north Chihli, but in the

[1] See Bailey Willis, *Econ. Geol.*, Vol. 3 (1908), pp. 15–27, for brief résumé of Chinese coals.

Cretaceous and Tertiary formations, if these are present, the ratios should be low.

PETROLIFEROUS INDICATIONS

Absence of seepages.—On attempting to trace down oil rumors, it was found that all reports, regardless of their source, referred to two limited occurrences of oil shale. Neither the most careful inquiries on the ground, nor letters and telegrams sent by the Chinese Oil Administration, elicited any reliable information of oil showings. Two samples sent from the single reported seepage proved to be fresh water with traces of a native cooking oil and refined kerosene evidently derived from the unclean containers.

Oil shales.—Oil shales were found and studied at two localities, Chuishaokua and Chenwoyau. At the former, 3 miles southeast of Santaidsi of the detailed German maps[1] (Long. 119° 15′ East, Lat. 41° 10′ North) at a point two-thirds of a mile north of the village, lense-shaped masses of bituminous shale, from 1 to 4 feet in thickness and 6 to 10 feet in length, were found exposed in several pits within distance of less than one-third of a mile. The lenses are essentially separate pockets, connected only by thin limes, or streaks of dark shale, resting on ordinary light shales and overlain by an 8-foot bed of medium-grained massive sandstone, followed by many feet of grayish or greenish shale.

The occurrence is in a structural basin, mainly of green shales and tuffs, with some melaphyre, probably intrusive, between Cambro-Ordovician limestone on the south and undetermined metamorphic rocks on the north, the total breadth of the basin being about 6 miles. The age is probably Jurassic.

The shale gives a rather weak bituminous odor when broken, and for many years has been mined on a small scale by pits for local use as fuel, but it burns with difficulty, and is of little practical use. No oil seepages were to be seen, although an adjacent property owner found traces of oil on the rock surface in 1912. Such exudations are to be expected where rock of this character is exposed to the direct rays of the sun. An examination of the shale at Shansi University in Taiyuanfu is said to have shown the presence of 12 per cent of

[1] Karte von Ost-China, *Kartographische Abtheilung der Kongl. Preuss Landes Aufnahme*, Mukden sheet, 1909.

kerosene. The amount of shale available is too limited for the deposit ever to be of commercial value.

The second occurrence of oil shale is in the hills about a mile southwest of Chenwoyau, 6 miles southwest of Schantsuidsi of the German map mentioned, and about 30 miles south of Kienchanghsien (Long. 119° 6′ East, Lat. 40° 55′ North). The formation consists of 1 to 2 feet of black shale which extends a distance of a mile or so along the valleys and hillsides adjacent to the village. It smells faintly bituminous when freshly broken. It has been burned experimentally in a few houses, but is not in general use as a fuel.

The bituminous shale occurs as a member of a thick series of soft shales and conglomerates, Carboniferous or possibly Jurassic in age, occupying a basin about 10 miles in width, with a NE.–SW. trend. High mountains of Cambro-Ordovician limestone bound it on the northwest, while similar ranges of undetermined rocks border it on the southeast.

This shale, like that at the first described locality, carries minute streaks of bituminous matter, not exceeding half an inch in length and one-sixteenth of an inch in thickness, which may indicate the former presence of free petroleum. The bed is not of sufficient thickness to be of material value, even when economic methods of distillation of oil shales are discovered.

OIL PROSPECTS

Basins of north Chihli.—Although it probably cannot be safely said that small exudations from oily shales will not be found nor that such shales may not, under especially favorable conditions, yield small quantities of oil under refining processes, it may be definitely stated that the production of petroleum on a commercial scale is highly improbable, if not impossible, in the disturbed area of northern Chihli, the metamorphism resulting from the sharp folding, faulting, extensive igneous intrusions, and other causes being sufficient to have expelled any oil that may have originally been present. The carbon ratio of 76 in the Carboniferous rocks is 11 points more than the highest found in any commercially productive oil field, and those of the Jurassic, if similar to the ratios (66 to 76) prevailing in rocks of the same age in Manchuria, are likewise higher than in any

known oil field.[1] They are not, however, such as necessarily to preclude the occurrence of natural gas in the Jurassic, although geologic conditions are apparently not favorable to large accumulations of this product.

Coastal plain.—No seepages of petroleum have, to the writers' knowledge, ever been reported, and no oil indications were found by Frank A. Herald, who crossed the coastal plain and examined many of the projecting masses of older rocks. Since the carbon ratios preclude the occurrence of oil in any quantity in the Carboniferous, and little is known of the position or structure of Jurassic, Cretaceous, or Tertiary, there is nothing whatever to encourage drilling at this time.

OIL PROSPECTS IN SHANSI

INTRODUCTION

Although the exploration of Shansi was not one of the objectives of the work in charge of the writers, it was necessary for several of the parties to cross the western half of the province en route to Shensi, their specific field of investigations. The routes followed, which are indicated on Figure 1, include those of V. H. Barnett and E. L. Estabrook in addition to those of the writers. The geology was mapped and sections made along each of the lines of traverse and, in addition, every attempt was made to verify reported seepages and to discover new ones.

FORMATIONS AND STRUCTURE

East Shansi basins.—Between the Fen Ho Valley of central Shansi on the west and the Chihli boundary on the east, and limited by the Honan boundary on the southeast and south, is a series of long, narrow, and usually sharp arches and basins involving ancient

[1] In general, carbon ratios of 50 or less are associated with heavy coastal plain oils, 50–55 with medium oils such as those of the Ohio-Indiana field of the United States, and 55–60 with light oils of high-grade fields. Oil has been found where the ratios are from 60 to 65, but commercial pools are rare. Above 65, commonly regarded as a deadline, no commercial production is known, although gas may occur. The relations of carbon ratios to oil, called to the attention of American geologists by David White, were, it is believed, first applied and extensively tested in the field by the present writers. For a summary of the earlier literature and more detailed explanations of the application of the carbon ratio principle, see Myron L. Fuller, "Relation of Oil to Carbon Ratios of Pennsylvanian Coals in North Texas," *Economic Geology*, Vol. 14, No. 7 (1920), pp. 536–42, and "Carbon Ratios in Carboniferous Coals of Oklahoma and Their Relations to Petroleum," *Econ. Geol.*, Vol. 15, No. 3 (1920), pp. 225–35.

crystalline rocks, Cambro-Ordovician limestones, and Carboniferous, Permian, and possibly later shales and sandstones (Fig 2). The high dips are accompanied by pronounced faulting, especially at the margins of the troughs, which are often of the graben type. Coals of considerable thickness are worked at several places.

Central Shansi basin.—This basin, coinciding mainly with the Fen Ho Valley, but including some of the lower hills on either side, extends with a bearing of about S. 30° W. from a few miles north of Taiyuanfu in central Shansi to a point at least as far south as Hungtung, a distance of about 100 miles, beyond which there may be an extension southwestward beneath the loess and alluvium of the lower Fen Ho Valley of Shansi and the Hwang Ho and Wei Ho valleys of Shensi. Its breadth is about 30 miles. On the east, it is bounded by mountains of granite, schist, or Cambro-Ordovician limestone, which separate it from the eastern basins, and on the west a similar range separates it from the western Shansi basins. Great faults are associated with downwarping on both sides of the graben. Coal-bearing beds (Shan-si formation) of Carboniferous and Permian age, 300 to 1,000 feet in thickness, are upturned on both eastern and western rims. Several coals are extensively mined on the east side, but the coals along the west rim are less actively worked. In parts of the basin, the coal-bearing formations are locally overlain by the red shales and sandstones of the Pu-hsien formation, probably of Permo-Triassic age. Dips are usually high, in many places 30 to 45 degrees, or more (Fig. 2).

West Shansi basins.—Between the sharp faulted anticline with Cambro-Ordovician, or granitic core, bounding the central Shansi basin on the west, and similar anticlines 10 to 20 miles farther west, is a series of elongated basins beginning near the Great Wall (Lat. 40° N.) on the north and extending to the vicinity of the junction of the Fen Ho and Hwang Ho. These basins[1] contain Shan-si coal measures, of considerable thickness, but the coals are worked at a few places only.[2] Dips are everywhere high.

[1] These basins are nearly always faulted and, for convenience, are spoken of as grabens.

[2] For a more detailed discussion of the Shansi coals see Myron L. Fuller and Frederick G. Clapp, "Revision of Coal Estimates for West Shensi, China," to appear in *Economic Geology*, December, 1926.

North Shensi basin.—The eastern rim of this basin, described in the section on the oil prospects of Shensi, lies in western Shansi, the boundary running in a southerly direction from the Hwang Ho near the Great Wall to the mouth of the Fen Ho (Fig. 2). The width of that part of the basin lying within the limits of Shansi averages 25 to 30 miles. The area is characterized by sharp folds flattening westward into moderate, monoclinal dips near the Hwang Ho, midway of the length of the basin, but retaining high inclinations in the north and south.

METAMORPHISM

The anthracitic nature of the coals of eastern Shensi affords the best evidence and measure of the alteration which the beds have undergone. Six analyses of coals from southeast Shansi show, according to N. F. Drake,[1] from 80 to 87 per cent of fixed carbon, 2 to 3.5 per cent of volatile matter, 1.5 to 3.5 per cent of water, and 6.5 to 14 per cent of ash. These figures would indicate carbon ratios higher than 95. No analyses from central or western Shansi are available to the writers, but the coals of the former are semi-anthracitic, and those of the latter, although bituminous, are probably characterized by carbon ratios higher than 70.

PETROLIFEROUS INDICATIONS

Reported seepages.—Petroleum seepages have long been reported from the coal fields of Shansi. Boverton Redwood[2] mentions oil indications "at Kiangtchu (Kianchow?) in the southwest and at Taitongfu (Tatungfu) in the north." Reports of oil from several other localities were made to the Chinese Oil Administration in 1914 as a result of inquiries among native officials. One of the latter stated that in the nineties of the last century the local government sent men through the province in search of petroleum and that in more recent years inquiries had been conducted by the University at Taiyuanfu, both without success. Chinese newspaper statements that there are forty places near Taiyuanfu where oil has been found may be imaginary interferences drawn from these inquiries, since in-

[1] "Coal Fields around Tsechou, Shansi," *Trans. Am. Inst. Min. Engrs.*, Vol. 30 (1900), p. 261.

[2] *Petroleum*, 3 vols., London and Philadelphia, 1913, Vol. 1, p. 159.

vestigations of W. E. Bryant and others show no local knowledge of oil in the Taiyuanfu district.

The reported oil seepages in Shansi include the following (Fig. 3):

1. *North Shansi.* "Kerosene" is said to have been tasted by a Norwegian missionary in a stream, not specifically located, in the north part of the province.
2. *Tatungfu.* Presumably "Taitongfu" of Redwood (*op. cit.*) near which his north Shansi occurrence is located.
3. *Paotechow.* Reports of two seepages northeast of this city, located on the Hwang Ho, were made to the writers.
4. *Yuhsien.* At this place, 15 miles north of Showyang on the Taiyuanfu railroad, oil was reported to W. E. Bryant as being brought into the city in small quantities in native containers from a seepage 20 miles distant.
5. *Chinghsinghsien.* A little oil was also reported to Mr. Bryant as coming from the vicinity of this station on the Taiyuanfu railroad.
6. *Liangtuchen.* A seepage was reported to the Oil Administration from the vicinity of this city, located on the Fen Ho about 80 miles southwest of Taiyuanfu.
7. *Lingshih.* Oil from this locality, 90 miles southwest of Taiyuanfu and 10 miles south of Liangtuchen, was reported to K. T. McCoy, a resident of the province who was associated with the writers as interpreter and manager.
8. *Hsiauyi.* There were similar rumors of oil at this town, northwest of Lingshih and near the mountains forming the west side of the Taiyuanfu plain.
9. *Yungningchou.* A report that oil was collected and used by natives near this locality, 80 miles southwest of Taiyuanfu and 30 miles from the Hwang Ho, may have been based on a local newspaper item referring to a supposed occurrence south of Lingshih, but Carboniferous beds occur in the vicinity.
10. *Shihlohsien.* At the south end of an anticline a mile north of the town, 110 miles southwest of Taiyuanfu and 10 miles east of the Hwang Ho, are several

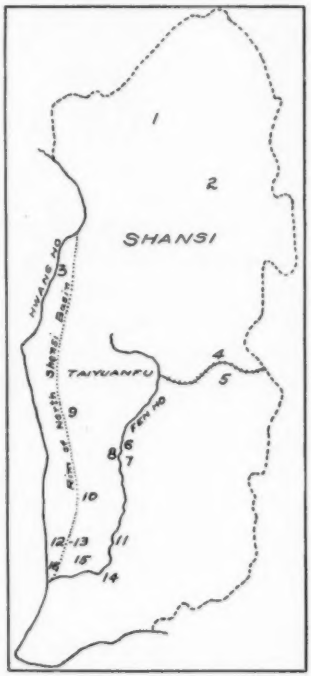

FIG. 3.—Map showing approximate locations of reported oil seepages in Shansi.

springs of fresh water and a round muddy pool from which gas was seen rising in small quantities at several places. There is undoubtedly buried organic matter in the mud, but the general and continuous escape suggests natural gas. The pool could not be approached close enough at the time of the visit to permit the taking of samples.

11. *Hungtung.* Oil has been reported from the vicinity of this city, situated on the Fen Ho 15 miles northeast of Pingyangfu in south Shansi.
12. *Taninghsien.* "Black oil" is reported coming from a "coal mine" in the mountains east of this city, 60 miles west and north of Hungtung, and is said to be collected and burned. It may refer to the seepage reported from Hungtung.
13. *Kichow.* Oil was reported to W. E. Bryant from Chichou, probably identical with Kichow, 50 miles west and a little north of Pingyangfu in south Shansi. The oil is said to have been collected in bowls and bottles, and burned, but although it is very cheap, it is unpopular because of its odor and smoke. Eleven other oil seepages were reported in 1908–9 to Harold K. Martin, Mining Engineer for the Pao Chin Mining Co. of Shansi, as occurring near several small villages near Kichow and adjacent parts of southwest Shansi. Samples from most of these were examined by E. T. Nystrom of the Shansi Imperial University at Taiyuanfu. No oil was found and the salt was less than in the city drinking water, but iron was present in quantities sufficient to suggest that iridescent scums of this substance might have given rise to the reports.
14. *Kiangtchow.* Oil is listed as occurring near Kiangtchu, probably Kiangchow on the Fen Ho some 50 miles above its junction with the Hwang Ho, by Redwood (*op. cit.*).
15. *Shihkiatan.* There have been persistent rumors of oil from this locality, but nothing but a hydrogen-sulphide spring, 17 miles north of the Fen Ho, could be located on the ground.
16. *Fen Ho.* A seepage reported on the Fen Ho near its mouth may be the same as the preceding.

Nearly all of the foregoing reported oil and gas showings, as well as others of which particulars are not now available, were investigated by E. L. Estabrook, V. H. Barnett, or the writers, but in no case could a definite seepage be located, or its existence established by eye witnesses.

In the adjoining province of Shensi, one of the writers saw oil escaping along a river through a distance of an eighth of a mile, although a few weeks later not a trace of it was to be seen. Many of the China seepages depend directly on the movements of shallow

groundwaters of meteoric origin, and are seen only after rains, when emerging water brings out oil along bedding planes which are normally dry.

The persistence and definiteness of many of the reports, taken in connection with the nature of the rocks (coal measures),[1] makes it probable that certain of the seepages have actually existed within the last few years, their non-occurrence at the time of the examination being attributed to unfavorable groundwater conditions. Experience elsewhere, however, shows that reports of a single definite occurrence may come from widely separated points, sometimes hundreds of miles apart, and it is almost certain that several of the reports refer to the same seepage. This is probably illustrated by numbers 10 to 16 previously mentioned. Except number 3, and possibly numbers 12, 13, and 16, locations of reported seepages fall within basins or graben areas, mainly of the Shan-si formation.

OIL PROSPECTS

The folding in Shansi is nearly everywhere sharp, and faulting is common and pronounced. Carbon ratios in the anthracites of the eastern and central basins are 25 to 30 points higher than what is considered the "dead-line" as regards oil production, and although ratios are undoubtedly lower in the bituminous coals of the western basins, there is no point within the areas of otherwise favorable formations which is more than 30 miles from the highly folded and faulted rims, a distance too short to render probable a decrease in the ratio to a point permitting the occurrence of oil in paying quantities. On the other hand, many seepages have been reported from the coal measures of the province, and some of them almost certainly have a foundation of fact.

It is probable that small seepages of high-grade oil will be found from time to time, and it is conceivable that under favorable conditions, wells might yield a few gallons or barrels of petroleum, but it is highly improbable that a paying field will be discovered. Conditions which would warrant drilling are not known to exist anywhere within the province.

[1] Carboniferous and lower Permian.

OIL PROSPECTS IN SHENSI

INTRODUCTION

The character of the rocks, their slight disturbance, and the seepages, as well as a real, though limited, production of petroleum at Yenchang, led to the general belief that a company with adequate capital and employing modern methods might develop paying fields in the province of Shensi. A concession was obtained by an American company in 1914 and the writers engaged to undertake the explorations.

CHARACTER OF WORK

The investigations were carried out in greater detail than in any other region examined in China, the entire province being crisscrossed with reconnaissance traverses by six geological parties and selected areas surveyed in detail by plane-table with instrumental determinations of dip. A line of stadia-levels was run from the end of the railroad at Taiyuanfu, Shansi, to the oil wells at Yenchang, a distance of about 250 miles, thence westward 35 miles to Yenanfu and southward 80 miles to Chungpu (Fig. 1). The following table gives the elevation of the towns along this line.

TABLE II

STADIA-LEVEL ELEVATIONS IN SHENSI*

Based on Line Run from Taiyuanfu (2,626′ A.T.) via Hwang Ho (2,100′±) at about Lat. 36° 30′ N.

	Feet Above Sea		Feet Above Sea
Sunchiachuang(Hwang Ho)	2,146	Choupeihyongho	2,912
Datsikou	2,826	Yenchang (Oil wells)	2,563
Tsingkienhsien	2,869	Ssushihlipu	2,973
Yenchwanhsien	2,507	Yenanfu	3,100
Liumachiakota	2,707	Sanshihlipu	3,456
Tuanchiakota	2,930	Laoshan	3,464
Shihyukou	3,052	Kanchuanhsien	3,216
Yungpingchên	3,084	Yulinchou	3,041
Wennanyi	2,845	Fuchow	2,966
Hochiayi	3,279	Tongyutsihchuan	3,683
Tongchiaping	3,009	Lochwanhsien	3,688
Kankouyi	2,880	Chioukoho	2,563
Lihokoa	2,843	Chungpu	2,694

* See note under Introduction, for significance of name terminations.

Since the bench marks are usually outside the towns, the figures are approximate only, but are close enough for all practical purposes.

The field work on geological structure presented unusual difficulties. The entire province lies in the great loess area of Asia, with a mantle of fine silt from 500 to 2,000 feet in thickness overlying the rocks. On all early maps of China, as well as on some of the latest general maps[1] the region is shown as loess without any indication of underlying formations. Richthofen did not visit the region, but has indicated Carboniferous as underlying the loess on the borders of the Shensi area. As a matter of fact, nearly every stream of consequence cuts through the loess into the underlying rocks, making it relatively easy to identify formations and to determine the general structure, although in places the considerable distance between streams makes the mapping of minor structural features difficult. This difficulty is further increased by the general lack of key beds and the prevalence of cross-bedding to the exclusion of normal stratification planes.

In general the dips, although instrumentally determined, could be measured only on the vertical faces of cliffs, 100 feet being a common maximum of continuity. Since the cliff faces seldom coincided in direction with the dips, the observed inclinations rarely represented true dips. In many cases it is impossible to find face dips at sufficiently large angles with one another to calculate the true inclinations of the beds. In spite of all these difficulties, hundreds of square miles were mapped topographically and geologically in great detail by Marquardt, Lovejoy, Barnett, Gale, and Hill under the writers' direction.

GEOLOGY

North Shensi basin.—Extending from the vicinity of the great northern loop of the Hwang Ho in the northern Ordos to the east-west Tsin Ling–Ta Hua mountain ranges in central Shensi and from the mountains of western Shansi to those of eastern Kansu, is the great North Shensi Basin of sedimentary rocks (Fig. 2). Its length from north to south is 450 miles, its width from east to west more than 250 miles, and its area more than 100,000 square miles.

[1] Bailey Willis and Eliot Blackwelder, *Researches in China*, Vol. 2, Plates 4, 5, and 6.

Surrounding the basin are areas of sharply folded and shattered Archean and Algonkian rocks. Between these and the main basin on the east, south, and west, and probably also in the Ordos on the north, there is a belt of grabens, largely in the thick Cambro-Ordovician limestone, but with some patches of overlying coal measures still preserved.

Inside the graben belt, Cambro-Ordovician, Carboniferous, Permian, Triassic, and Jurassic formations form successive belts dipping into the basin on the east and south. The beds are highly inclined at the outer margin, but the dips rapidly decrease through a series of folds to a nearly uniform inclination of about half of a degree at a distance of 30 miles or so from the rim. The Ordos was not explored and the relations on the north were undetermined. On the west, the graben zone of Cambro-Ordovician and Carboniferous rocks was alone noted, but since this occurs within a few miles of the nearly flat upper Jurassic beds, it is probable that the 15,000 feet or more of post-Carboniferous basin beds are not repeated but abut against great faults beneath the thick loess of eastern Kansu.

Local unconsolidated Cretaceous and Tertiary gravels, and the great loess sheet lie unconformably upon the upturned and beveled basin beds. The distribution of the principal formations is shown on Figure 4.

STRATIGRAPHY

Tung-chuan quartzite.—The earliest basin beds consist of reddish quartzite with some red shale, commonly having a thickness of about 500 feet and resting unconformably on the beveled and locally peneplained Archean and Algonkian surface. They are the equivalent of the Man-to red shales of Willis and Blackwelder in eastern Shansi and of the San-yuen freestone phase of central Shensi. Their age is probably late Lower, and early Middle Cambrian.

Ki-chou limestone.—This is a hard, fine, gray, buff or brownish marine limestone, commonly massive and unfossiliferous, attaining a thickness of 4,000 to 5,000 feet and generally resting conformably on the Tung-chuan quartzite but in places lying unconformably on the Algonkian or Archean. With the preceding formation, it occurs in horsts or in great folds in the disturbed marginal zone of the basin. The name was applied by Willis and Blackwelder, who assigned it to the Sinian division of the Cambro-Ordovician.

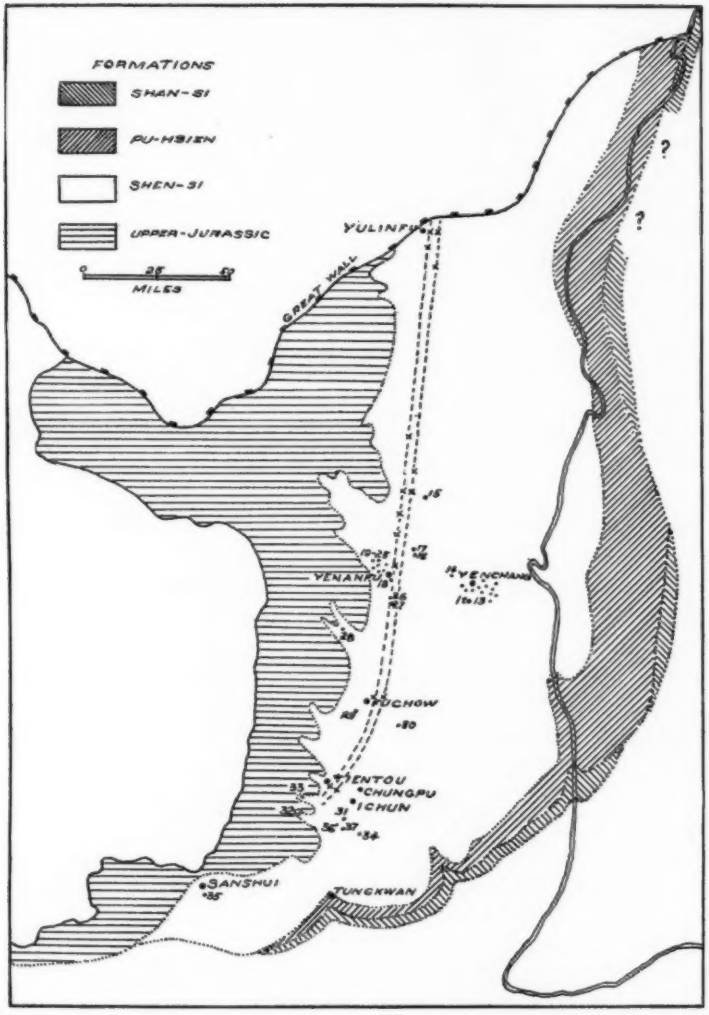

FIG. 4.—Map showing principal formations and seepages of northern Shensi and western Shansi. (Outcrops are only partially corrected for topography. Wells 1–5 are at Yenchang; well 6, near Seepage 15; well 7, east of seepages 19–25, wells 8 and 9, between Tientou and Seepage 33; and well 10, about 13 miles northwest of Tungkwan.)

Shan-si formation.—This formation consists of shales and sandstones of normal coal-measure types. In the basal portion, sandstones and shales alternate in something like equal proportions; in the middle, black shales and coals predominate, with a little limestone; in the upper part, sandstones, with a little red coloration in places toward the top, constitute the greater part of the beds. The thickness is commonly from 300 to 500 feet, but in some sections reaches 1,000 feet at the outcrop and may be greater beneath the overlying beds in the center of the basin. The formation is represented in synclines or grabens around the rim of the basin as well as in a nearly continuous outcrop inside the Ki-chou limestone on the east and possibly elsewhere. It rests unconformably on the latter, but with little difference in dip. Its name was given by Willis and Blackwelder, who regarded it as of Carboniferous (Pennsylvanian) age, but subsequent paleontological examinations by the China Geological Survey apparently indicate that the upper half, including the higher coals, is "Permo-Carboniferous."

Pu-hsien formation.—This formation consists of 1,000 to 2,000 feet or more of thick buff sandstones alternating with red shales which tinge all outcrops with red. They grade into the Shan-si beds at the base. They were formerly designated by the writers as Fen-ho (Fön-ho), but this term has been abandoned because of its prior use in another sense. The beds were classed as "Uebercarbon" (Permian?) by Richthofen, and Willis and Blackwelder, under the term "Red Beds," designated them as Permo-Mesozoic. The China Geological Survey describes them as "Triassic, lower part probably Permian." The formation, besides occurring locally in a few basins outcrops in western Shansi in a belt lying east of, and parallel to, the Hwang Ho from the vicinity of the Great Wall to the vicinity of the falls of the river mentioned, thence south along the latter 40 or 50 miles, finally bending southwestward across central Shensi. The red color disappears west of the longitude of Sianfu and the formation, if present, is not easily distinguished from the Shan-si or Shensi beds. The character of the beds is shown by Figure 5.

Shen-si formation.—The Shen-si formation, which has a total thickness ranging from 6,000 to 7,000 feet, rests with a transitional contact on the Pu-hsien beds. Its lower part consists of dense,

hard, fine-grained, shaly or platy, generally cross-bedded, gray sandstone; the middle includes ordinary and carbonaceous shales, several coals, and one or more thin limestones, with thick, massive, buff sandstones at the top and bottom, in which cave dwellings and rock temples are common; the upper part is predominately gray or pink sandstone, with some shale. Oil seepages are found in all three

FIG. 5.—Steeply dipping beds of Pu-hsien formation capped with loess, 1½ miles north of Chowchiashihyao, northeastern Shensi, near Fukuhsien.

phases.[1] The formation outcrops in western Shansi in a belt 90 miles long and 15 miles broad between latitudes 36° and 37° 20′, and forms the surface rock throughout the greater part of Shensi north of Latitude 34° 20′. The China Geological Survey, apparently on the basis of plant remains collected near the coal horizons in the center of the formation, refers it to the Jurassic. Figure 6 is a view of typical Shen-si beds of the Yen-chang phase. Figure 7 shows a pyrite bed and massive sandstone near the top of middle or Yen-an-fu phase of the Shen-si formation.

[1] These three divisions are known as Yen-chang (basal), Yen-an-fu (middle), and Tien-tou (upper) phases.

Formations above the Shen-si.—At the top of the Shen-si formation is a red shale zone, with interbedded limestones in the north and some sandstones and a little conglomerate in the south.[1] The total thickness is 100 to 500 feet, and the zone, which is regarded as transitional, extends southward from the vicinity of the Great Wall

FIG. 6.—Gently dipping beds of Shen-si series on the Hwang Ho, looking downstream from Chingshuikwan, Shensi.

in Longitude 109° East parallel to, and about 40 miles east of, the Kansu boundary to the vicinity of Chungpu, thence southwestward and westward toward Lungchow. It is assigned to the Upper Jurassic by the China Geological Survey on the basis of fish remains.

Above the transition zone and lying just east of the Kansu border with limits similar to the preceding, are about 2,000 feet of very massive, but generally false-bedded, light buff sandstone with some red stains.[2] The China Geological Survey assigns this to the Upper Jurassic.

[1] An-ting and I-chun formations (Table I).

[2] Lo-ho formation (Table I). The cross-bedding is well shown in Figure 8.

Above the false-bedded sandstone about 1,000 feet of fairly regularly bedded reddish sandstone are recognized along the Kansu border, supposedly also Jurassic in age.[1]

In the northwest arm of Shensi and in eastern Kansu is a series of green and red shales having an outcrop 75 to 100 miles in width and extending to the western rim of the basin. The beds have a probable thickness of 3,000 feet, of which only the basal strata are exposed in Shensi. The China Geological Survey has assigned the series to the Cretaceous, but since the beds follow known Jurassic deposits without interruption and are fully consolidated and tilted and beveled by the Cretaceous peneplanation, they are retained in the Jurassic by the writers.[2]

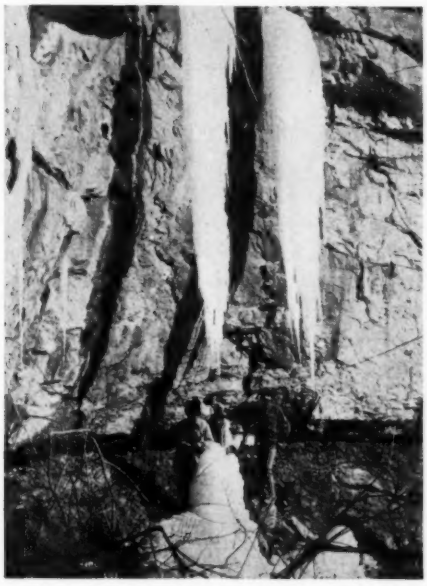

FIG. 7.—A prominent key bed near Chê-ts'un, district of I-Chuh-hsien, western Shensi. (The black band behind the men and below the massive sandstone is a conspicuous sedimentary pyrite bed of wide distribution.)

The thick, mainly unconsolidated, white to orange gravels, sands, and clays resting unconformably upon coal-bearing strata near Lungchow and elsewhere in western Shensi have yielded fish remains which appear to indicate a Cretaceous age. At most places, however, the sub-loess gravels are probably Tertiary. The main loess deposition appears to have begun in late Tertiary and continued through the Pleistocene, during which period 500 to 2,000 feet of deposits accumulated.

[1] Hwa-cha formation (Table I).

[2] Hwan-ho formation (Table I.)

STRUCTURE

The general structure has been indicated in the description of the North Shensi basin. As there stated, the dips rapidly decrease from the high angles at the rim through a series of decreasing folds until, at a distance of 25 to 30 miles, they become essentially monoclinal with inclinations of about half a degree, or 50 feet, per mile away from the margin. The monoclinal dips are broken by a few flats, or terraces, but these, with one or two exceptions, are not pronounced. Well-defined anticlines or domes are absent except near the immediate margins. Normal faults are not uncommon, but are of small throw except near the rim. No upturning of the basin beds on the west has been observed, great faults apparently constituting the boundary on that side.

FIG. 8.—Cross-bedding in Lo-ho sandstones near source of the Yenshui, northern Shensi. Photo by E. L. Estabrook.

On the south, the folding and faulting are more pronounced, the disturbance affecting horizons as high as the middle phase of the Shen-si formation in central Shensi, although on the east even the basal part is generally monoclinal. The graben zone alone appears to be represented on the west.

METAMORPHISM

No analyses of coals from the North Shensi basin are available, hence the carbon ratios, which normally afford the best measure of metamorphism, are undetermined. In eastern Shensi, the ratios are

probably lower than those of western Shansi, since the sharp folding and faulting are generally absent. The coals of the Carboniferous and Permo-Carboniferous Shan-si formation are bituminous and the carbon ratios should not be prohibitive to oil, but the formation for the most part lies beyond the limit of practicable drilling at this time. Along the more highly disturbed southern rim of the basin, the carbon ratios of the Shan-si formation are likely to be prohibitive.

The gravity of the Jurassic oil at Yenchang, 65 miles from the east rim of the basin, according to field tests made by Clapp, averages 35°–36° Be. (corrected to 60° F.), which is not far from that of Oklahoma oils, and corresponds to a probable carbon ratio between 50 and 55. Carbon ratios of 60 or lower, which are considered favorable to the occurrence of oil, are therefore apparently to be expected in the Jurassic formations west of the Hwang Ho in the part of north Shensi lying northwest of a line drawn southwestward from the falls of the Hwang Ho to the vicinity of Yichuan and Ichun, in west-central Shensi.

OIL SEEPAGES IN SHENSI

Oil seepages of a permanent character have been known in Shensi for hundreds of years. According to a recent undated report of Ho Hsi-chin, the oil of Yenchang was mentioned more than 200 years ago in the *Ta Min I Tung Chih*, or *Chronicle of the Great Ming Dynasty*, and in the later *Chronicle of the Great Ching Dynasty* under the caption of "Hills and Rivers" it is recorded that the oil can be used for both fuel and lighting and has medicinal properties, curing skin diseases of man and animal. Records of the seepages are also found in *Fang Yu Chi Yao*, or *Concise Geography*, by Ku Chu-yu, and in the Prefectural Record and District Record of Yenchang.

The attempt to verify the unusually large number of reported seepages led to the discovery of sixty-three actual occurrences. Some of these were of transient character, nothing whatever being later observable at certain localities where a few weeks, or in some cases a few hours, previously very definite escapes of oil had been seen by the geologists themselves. Their disappearance seemed to be the result of changes in groundwater movements or to the rise of the streams.

In Shensi, where the natives are familiar with the appearance of petroleum, the mistaken identification of iron scums for oil seldom occurred, and it is not improbable that most of even those seepages which the geologists were unable to verify have actually existed in the recent past. In view of the large number of unverified seepages, however, and their lack of special significance in a region where the escape of oil is to be expected almost anywhere and in which definitely established seepages are plentiful, it has been thought best to omit the unverified occurrences from the discussion of Shensi and to include only those actually seen or verified. Thirty-seven of these are here given, their locations being indicated on Figure 4. About twenty-five additional seepages were located toward the close of the work, mainly by Frank A. Herald, E. L. Estabrook, J. M. Lovejoy, Ernest Marquardt, L. E. Gale, and A. D. Hill. The records of these are not available, but the oil shows were of the same general character as those here described. In every instance the present escape of oil was very small and the seepages were not associated with material accumulations of tar.

1. *Changchiawan (or Isaochiakodor).* This seep is situated near water-level on the north bank of the Yenshui, about 3½ miles west of Yenchang near the village of Changchiawan. It consists chiefly of dark oil stains on the surface and in the parting-planes of a fine-grained, somewhat shaly sandstone. Little oil seems to exist within the pores of the rock itself. Water issuing from the rock after a rain increases the exudations. A small spring of bubbles, ½ to ¾ inch in diameter, having an odor resembling natural gas, was noticed a few feet upstream from the oil seep. When covered with water, small globules of oil rise to the surface and form a thin film there.
2. *Chiaochiashihkou.* This seep is situated about 2 miles above the mouth of a small creek entering the Yenshui about 1½ miles west of Yenchang, near the tiny hill village called Chiaochiashihkou. The oil emerges as a moderately thin liquid from two points a rod apart, coming from a stratum of blue shale about 2 feet in thickness exposed in the bed of the stream. The exudation is small in quantity, being just enough to form a thin film on the surface of the water, and to leave a little deposit of tar where it comes out.
3. *Yenchang No. 1.* This seepage, the nearest to the city of Yenchang, consists of small globules of oil rising at intervals of several feet from the bed of the Yenshui about two-thirds of the way between the west gate of Yenchang and the ravine entering the valley from the south.
4. *Yenhcang No. 2.* The second Yenchang seepage is on the south bank of the Yenshui one-fourth mile below the city. A very small deposit of black tar,

apparently coming from bedding planes of the compact shaly sandstone, was observed, although nothing seemed to be emerging at the time of visit.

5. *Yenchang No. 3.* Although situated on the Yenshui only a mile below the city and the largest of all the seepages seen in the vicinity of Yenchang, it had never been known until discovered by one of the writers' parties in November, 1914. When first visited oil was coming up in the river in small globules at several places in a distance of 1,500 feet, or rising through the wet sand along the banks and trickling into the stream. Oil was also emerging from the rock above the water and forming little pools on its surface. Small amounts of tar occurred in the bedding planes of the compact shaly sandstone. Wishing to collect samples, the party returned the next morning but the river had risen in the night, and only small globules were rising through the water. In the bank of the river near by is a small "hydrogen sulphide spring."
6. *Huchiachuan No. 1.* This seepage is situated a few hundred yards west of the small village of Huchiachuan, about 3 miles below Yenchang on the east bank of a small creek, known as Yenwukou, entering the Yenshui from the north. The seep consists of several exudations of tar issuing from a thin bed of blue shale under an overhanging ledge of cross-bedded sandstone, over the top of which the trail passes toward Yenchwan.
7. *Yenwukou.* This seepage is on the opposite bank of the same stream 1½ miles above the preceding seepage, and about 1½ miles east of Yenchang, in an air line. The oil issues from a shaly sandstone beneath the water surface, rising in small drops which quickly dissipate. A pint or more of tarry material was gathered from the bottom of the stream, only a few inches deep at the time. The oil appears to emerge near the crest of a faint local dome, possibly along a minute fault, with a slip of a few inches, which cuts the dome at this point.
8. *Huchiachuan No. 2.* The second Huchiachuan seepage is in the bank of a small creek about ⅔ mile above the Yenshui. It is one mile southwest of the village and 2½ miles southeast of Yenchang. The seep is very small, only a small tar deposit being formed on the surface of the compact shaly sandstone in the bank of the creek.
9. *Kwantsunyungkou No. 1.* The first Kwantsunyungkou seepage is situated 1 mile north of the village of Paichiachuan 4½ miles east of Yenchang, the oil emerging from the cracks of a compact shaly sandstone in the creek bank and appearing as globules on the surface of the water.
10. *Kwantsunyungkou No. 2.* The second seepage at this locality is situated about 2,000 feet north of the first and on the same stream. The seepage consists simply of a black strain, smelling unmistakably of petroleum, on the face of a rather porous sandstone ledge in the bank of the creek.
11. *Kwantsunyungkou No. 3.* In the bed of the same creek as numbers 1 and 2, and about 1,300 feet upstream to the north is Kwantsunyungkou No. 3.

Oil in very small quantities oozes from the cracks and joints of the compact sandstone in the bed of the creek along a distance of 50 feet horizontally. It emerges so slowly that evaporation takes place as fast as it comes out, and only a tarry deposit remains.

12. *Liaotzuyuan.* This seepage, one of the historic Yenchang occurrences, is situated 5 miles southeast of Yenchang and ½ mile up a small creek southwest of the village of Liaotzuyuan. Oil is issuing from the cracks in the rock along the ledge above the creek and also in the creek bed in sufficient quantity as to be clearly seen. Natives are said to have formerly collected oil from the seepage and from a 10-foot dug well, the oil being removed from the surface of the latter with a ladle (Fig. 9).

FIG. 9.—An oil seepage staining cliffs 8 miles east of Yenchang, Shensi. Photo by E. L Estabrook.

13. *Tzuwangchuan.* In the early days of the Yenchang field, oil seeped from a creek bed at a point about 1 mile north of the village of Tzuwangchuan and 6 miles east-northeast of Yenchang in an air line, but no trace of it could be found in 1914.
14. *Tingchihli.* An old resident declared that 6 years before he had collected oil from a spot since covered with silt and grassed over, in a small ravine near the little village of Tingchihli, 7 miles up the Yenshui from Yengchang.
15. *Shihyukou.* The most northerly seepage in Shensi, so far as is known, is situated at the village of Shihyukou, about 3 miles southeast of Yungpingchen, and 20 miles northwest of Yenchwan, District of Yenchwanhsien. Shihyukou is a rather common name in Shensi Province, signifying "Rock-oil ravine." The seepage is one of the largest in northeastern Shensi, the oil showing at a number of points along the Yungpingchuan (river) and on its

banks for several hundred feet. The exudations, which are mainly small, rise through the muddy sediments of the stream bed, but at least one is from the parting planes of a shaly sandstone outcropping in the water. Bubbles of inflammable gas were also noticed rising in the river. Like the seepages near Yenchang, that at Shihyukou is of historical interest, a well curbed with stone having been sunk some years ago to a depth of 20 feet and oil collected for local use and testing. The well was reopened to a depth of 8 feet at the request of the writers in December, 1914, with the result that oil accumulated on top of the water in quantities sufficient to make possible the collection of several quarts. Through an accident, the laboratory test was inconclusive, but the oil was of light green color and sweet odor, suggesting a petroleum of excellent grade.

16. *Kangchiaping.* An aged native stated that until recently oil showed in the bed of a small creek near this village, 10 miles northeast of Yenanfu, but the spot is now covered by a huge mass of rock fallen from the ledge above. There is a small bulge in the strata at the point in question.

17. *Changchiachu.* On the same creek, one or two miles north of the previously mentioned locality and 11 miles east of Yenanfu, is a small "sulphur spring" (H_2S) near which the landowner declared oil had been showing until recent floods covered the place with silt. He stated that a company had been organized some years ago to develop the oil, but that the plans were later abandoned on account of the Boxer uprising.

18. *Yenanfu.* Tar was found filling the parting planes of the sandstone at the base of the cliffs on the west side of the valley outside the south gate of the city.

19. *Nanchiatou.* A black stain appears on the surface of a sandstone cliff on the Yenshui opposite Nanchiatou about 3 miles north of Yenanfu. Samples of the tarry residue were collected.

20. *Choupingkou.* Tar is smeared over an area 6 to 8 feet long by 2 feet broad on the face of a black-shale cliff 4 feet above the bed of Choupingkou creek, a tributary of the Hsi Ho, about a mile south of the village of the same name and 3 miles northwest of Yenanfu. There is a second but smaller exudation 10 feet from the first.

21. *Tungchiakou.* About 3,500 feet west of the last-mentioned seepage, $\frac{3}{8}$ mile south of the village of Tungchiakou and $3\frac{1}{2}$ miles northwest of Yenanfu, is a small oil seep in the bottom of the ravine known as Tungchiakou, or Shihyukou ("Rock-oil ravine"). The oil spring is at the base of a 20-foot cliff of local sandstone, a lense in the shales overlying the thick Yenanfu sandstone, which dies out within 150 feet to the north. Oil was formerly collected for local use in lamps from the surface of the water in a dug pit 2 feet in diameter. Oil is also reported as having been collected from another pit 30 feet distant. A little black oil is still to be seen in the first.

22. *Houchiakou No. 1.* An important seepage existed until recently at the base of a cliff on the west side of a branch ravine near the mouth of another Shihyukou, or "rock-oil ravine," on the south side of the Hsi Ho Valley 1½ miles west of Houchiakou and 6 miles northwest of Yenanfu. An old resident who had personally collected oil there stated that until a few years ago this seepage was among the largest and best in the region, the natives coming for miles to collect the oil for use in lamps, but that about 1910 a heavy flood covered the seepage with mud, the river taking a new channel at the time.

23. *Houchiakou No. 2.* In the valley of Houchiakou, ⅜ mile south of the village of same name, 4½ miles northwest of Yenanfu, and ¾ mile west of Tungchiakou, a small seepage was noticed in the creek bottom underneath an overhanging ledge of blue shale.

24. *Paichiachuang.* This seepage consists of a small oil stain on a cliff located 900 feet west of the village of Paichiachuang, on the north side of the Hsi Ho Valley, about 8 miles northwest of Yenanfu.

25. *Chiakou.* A seepage is reported about 5 miles northwest of Yenanfu, on the west fork of the Houchiakou Valley near the village of Chiakou.

26. *Komênshang No. 1.* In another "shihyukou" ravine, about 7 miles south of Yenanfu and midway between the villages of Komênshang and Ershihlipu, slight scums and globules of oil were found on the surface of the water in a small ravine. The strata dip locally toward the west at the unusual angle of 3 degrees through a distance of several hundred feet, the rocks being dark splintery shales with interbedded shaly sandstone lying some distance stratigraphically above the thick Yenanfu sandstone. The natives are reported to have collected oil here about ten years ago by skimming with pithy cornstalk cores, which, when saturated, were burned for lighting purposes.

27. *Komênshang No. 2.* About 7½ miles south of Yenanfu and half a mile south of the last-mentioned seepage, is a good oil seep close beside the main valley. A small amount of oil emerges from a hole 1½ feet across and one foot deep located about 10 feet west of the stream and 50 feet west of the base of a shale cliff. The latter consists of 40 feet of dark shale overlain by 30 feet of sandy shale upon which lies 10 feet of massive sandstone. The formations are horizontal along the creek in a north-south line, but the inclination was not exposed in an east-west line.

28. *Shatzewan.* The head man of the village of Shatzewan, a small village about 23 miles up the Lo Ho, northwest of Kanchuanhsien, stated that his father formerly collected and burned oil from the bed of a ravine about ⅔ mile north of that village. At the time it was visited, however, the place was so covered with mud that the oil did not show, but it is said to appear following winter and spring rains.

29. *Fuchow (Fuhsien).* About 4 miles southwest of Fuchow, on the main trail to Kansu Province, thin films of oil were seen on the surface of a few small pools along the stream. So far as could be determined, the oil exudes from the shale in which the stream bed is cut.

30. *Sanchunyi.* A shaly sandstone locally impregnated with what was apparently an oil residue was found about 20 miles northeast of Tientou.

31. *Kwanpingkou.* About 7 miles southwest of Ichun, a short distance up a side valley from the village of Kwanpingkou, is a small patch of tar, perhaps a foot square, in the bottom of the ravine. The oil, which appears to emerge at the base of a cliff from a thin bed of slabby sandstone underlain by shale, forms persistent scums on the water. The formations are inclined to the west at an angle of about 1 degree. No faulting of the rocks could be discovered in the vicinity, but great faults exist within a few miles, both to the north and south.

32. *Ishih'sun.* There was formerly a conspicuous seepage at a point a short distance south of Ishihts'un, 20 miles southwest of Ichun. Mr. Yu, of the Yenchang Oil Works, some years ago secured half a barrel of oil from it, and samples were given to the geologists by a nearby magistrate, although no oil was issuing from the site at the time. The seepage is closely associated with some fine coal beds that occur near the base of the red sandstone overlying the Shensi series of rocks, here generally uptilted and broken by faults.[1]

33. *Shihwan.* This seepage, not far from the village of Chiachuho, 5 miles northwest of Ishihts'un and 15 miles southwest of Ichun, consists only of tar in the crevices of a thin sandstone overlain by a dense blue shale.

34. *Sanshihlipu.* About 2 miles east of Sanshihlipu (or Liachuan) and 7 miles south of Ichun, is a small seepage, from which a few spoonfuls of oil were collected. The seepage is in the bed of a small intermittent stream, the oil apparently emerging from the soft yellow shales which become prominent toward the top of the Shensi series. It is stated to be of about the same horizon as the Ishihts'un but much above that of the Kwanpingkou seepage.

35. *Sanshui.* Tar was found filling the cracks of a blue and drab sandy shale at a point 4 miles south of Sanshui. Several hundred pounds of the substance had been taken from the seep for use as medicine. The seep is believed to be well above the series of thick sandstones and shales which appear at Yenchang, as are probably all of the seepages visited by the geologists in the Ichun region.

36. *Yushuits'un.* Until a few years ago, it is said, black oil flowed from the base of a cliff of sandy shale and shaly sandstone on the west side of a shihyukou or "rock-oil ravine" which enters the main valley opposite the Temple of Yushuits'un, ¾ mile east of the village of the same name and 7 miles south-

[1] See pages 32 and 33 should appear about 15 miles south of locations shown on Fig. 4.

west of Ichun. At this locality, 2 miles south of, and essentially at, the same horizon as the Kwanpingkou seepage, the oil is said to have risen through the water and formed gradually expanding circles of iridescent scum. The dip is north at a rate of 1:100.

37. *Chinniuchuang.* By crawling beneath an overhanging ledge of slabby sandstone in a deep ravine, half a mile northwest of Chinniuchuang and 7 miles southwest of Ichun, a few drops of oil were found oozing from the rock. The occurrence, which has been known for many years, is about 1½ miles south of the Yushuits'un seepage.

Seepages 1–14, 30–31, and 34–37 are in the lower, or Yenchang, phase of the Shen-si formation. Numbers 15–19, 26–27, and 32–33 are in the middle, or Yen-an-fu, phase, and numbers 20–25 and 28–29 in the upper or Tien-tou phase.

OIL WELLS IN SHENSI

Chinese wells.—With the increasing penetration of foreigners into the interior of China in the last part of the nineteenth century not only was the attention of outsiders drawn to Shensi petroleum, but the Chinese themselves were awakened to its possible value.

During 1901, 1902, and 1903 two natives, Yu Yen-piao of Tali-hsien and Liu Teh-hsin of Yenchang, co-operating with a German named Hannocken and the Shih Chang Company, a German firm, negotiated with the Foreign Office for an oil concession at Yenchang, but were opposed by the Governor of Shensi. A strong anti-foreign feeling was stirred up and a petition sent to the Emperor that the oil be developed only by Chinese.[1]

The Peking government, either not interested or not having the necessary funds, apparently authorized the local authorities to develop the Yenchang field. Oil samples were collected and sent to K. Inami of Wuchang, who reported 20 per cent of "lamp oil," 80 per cent of "heavy oil," with little paraffin.[2] Mr. Inami then (1905) sent a party to investigate the conditions. This party reported no trace of early borings or dug wells, but noted oil seeping out on the ground

[1] Descriptions of the early development of the Yenchang field are based on native accounts of K. Inami, who made the first official investigations for the government, and Ho Hsi-chin who also made a report and estimates for the development of the oil. Dates and statements are sometimes conflicting.

[2] Other analyses are said to have been made by Apuchen Chihlang, a Japanese chemist at the Sianfu College in central Shensi.

at many places. As a result of these findings, Mr. Inami recommended an experimental boring, and was authorized by the Provincial treasurer to purchase boring machinery and hire the necessary men. The machinery was obtained in Japan and transported from the railway at Honanfu by the roundabout cart-road in the soft loess via Sianfu in central Shensi and Yenanfu, west of Yenchang, a distance of more than 400 miles. The rig, which arrived at Hankow in August, 1906, was transported, set up, and drilling started in April,

FIG. 10.—The old Chinese oil refinery; one of the Chinese wells (right) and the first American test well (left); Yenchang, Shensi. Photo by V. H. Barnett.

1907, on land which had been secured immediately west of the city of Yenchang. Waiting for additional tools from Japan and the usual breakages delayed the work so that it became necessary to extend the limit of the contract six months. On October 17, 1907, oil rose to the surface from a depth of 230 feet and a few days later the well was completed at 250 feet. The initial yield was about 60 barrels a day. The cost, which the Chinese considered enormous, is given as $17,000 gold.

A small refinery was erected (Fig. 10), but owing to the dismissal of the Provincial treasurer, under whose authorization the previous work had been done, the oil situation was very unsettled. A new treasurer sent Chinese students to Japan to study oil methods. On

their return they assisted in the organization of the Shensi Oil Company, popularly financed by Shensi people, which took over the field in 1908, placing S. Ohtsuka, formerly chief engineer of the Nippon Oil Company of Japan, in charge of operations. It is reported that two additional wells (Nos. 2 and 3) were drilled by the Shensi Oil Company in 1910, or 1911, the first yielding a few barrels from a depth of 370 feet, and the second producing only a show of heavy oil.

FIG. 11.—The first American well, Yenchang, Shensi. (For views of other wells, drilling machinery, and supplies see Figs. 10, 13, 14, and 15, Vol. 3, pp. 99–116, of this *Bulletin*.

All wells are said to have been located on the basis of a geological map prepared by one of the Japanese engineers, who, though seemingly having some book-knowledge, evidently had little field experience. The map, which was seen by the writers, shows that crossbedding was mistaken for dips in almost every place. The knowledge that valleys are anticlinal in many parts of the world led the compiler to draw an anticlinal axis paralleling the local stream in all its sinuosities. Only the dips favoring this supposed structure were plotted, all others being disregarded.

Owing to lack of funds and unprofitable operations, as well as to

conflicts with native authorities, the Japanese engineers and workmen were released in June, 1911. A few months later the revolution put a stop to all operations, and the wells and plant were idle from the autumn of 1911 to August, 1912. They were then placed under the control of the republican governor of Shensi, under whose direction a fourth well was sunk in 1913 to a depth of 400 feet, but without securing oil.[1]

American wells.—In 1913 negotiations for oil privileges in Shensi were begun between an American company and the Chinese republican government, the concession eventually being signed early in 1914. A deep test in the Yenchang locality was decided upon by the company and a well (No. 5) (Fig. 11) was sunk west of the city to a depth of 2,270 feet. Shows of oil were obtained at 170, 255, and 365 feet, but the balance of the hole was dry.

Five other wells were drilled by the American company in Shensi from 1914 to 1916, mainly after the return of the writers to the United States. The locations, depths, and oil shows in the American wells are given in the following table. Depths of wells and

TABLE III

AMERICAN WELLS

Well*	Location	Total Depth (Feet)	Depth of Oil Showings (Feet)
5. Yenchang.....	800± ft. west of city gate	2,770	175, 255, 365
6. Yungpingchen..	35 mi. NW. of Yenchang	2,000	418
7. Yenanfu.....	2½ mi. NE. of city	3,000	1,145, 1,266
8. Tientou 1.....	2 mi. SW. of village (Chungpu District)	3,545	280, 1,003, 1,378, 1,420, 1,776
9. Tientou 2.....	5 mi. SW. of village (Chungpu District)	2,500	1,700
10. Tungkuan.....	13 mi. NW. of city	2,800	?

* Numbers begin with No. 5, following the four Chinese wells.

oil shows are based in part on the paper of T. O. Chu.[2] Several errors of location have been corrected.

Well No. 5 began in the gray sandy shales and sandstones of the

[1] The four Chinese wells are erroneously stated to have been sunk by the Chinese Bureau of Mines in a paper by T. O. Chu of the Geological Survey of China. This Bureau did not come into existence until the last of them had been drilled in 1913.

[2] *Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), p. 172.

Yen-chang phase of the Shen-si formation and reached the Pu-hsien red shales, but stopped 2,000 feet above the Shan-si coal-bearing formation. No. 6 began in the Yen-an-fu phase of the Shen-si series and stopped 1,000 feet or more above its base of the latter. No. 7 began in the Yen-an-fu phase and probably stopped about 2,500 feet above the base of the Shen-si. Nos. 8, 9, and 10 began near the top of the Yen-an-fu phase and lacked 2,500 to 3,500 feet of reaching the bottom of the Shen-si formation.

The sites of Nos. 5 and 6 were determined by proximity of seepages and general, rather than geological, considerations, although very faint structural terraces were utilized. Nos. 7 and 8 were located on more pronounced terraces, No. 9 on a weak dome, and No. 10 on a rather sharp local anticline characterized by faulting and dips of several degrees.

PETROLEUM PRODUCTION IN SHENSI

None of the Shensi seepages is of important size, the largest producing, at the maximum, only a few quarts of oil per day, hence their yield from a commercial standpoint is negligible. The only present production is from two of the Yenchang wells.

Well No. 1, at its completion in 1907, gave about 25 barrels of oil, mixed with water, per day, but shortly thereafter, it is said, the oil production increased to 60 barrels. Although the Chinese engineer in charge at the time states "the oil came up to the surface," pumping by steam was resorted to practically from the start. The second well, completed in 1910, or 1911, and having an initial production of perhaps 5 to 10 barrels per day, was pumped by a lever operated by five coolies.

The production of both wells fell off rapidly, and difficulties resulting from the influx of fresh water soon became serious. This led to a peculiar system of operation, the pumps being operated for raising water alone 2 or 2½ days; then, when this had been removed, or lowered, so that oil could enter, the latter was pumped 2 or 3 days. When the latter was in turn exhausted, the well was left 5 or 6 days for the oil again to accumulate. The total cycle of operations was about 12 days, 2 or 2½ "runs" or "workings" being undertaken per month. Pumping of water in well No. 2 took only half a

day, but the oil was exhausted in a few hours, and some days elapsed before the well could again be pumped. The average monthly output from both wells under the Manchu dynasty was 70 to 90 barrels per month.

After the 1911 revolution the new government, in attempting to deepen well No. 1, succeeded in flooding it with fresh water, later controlled in part by a series of four 2-inch pipes. At the end of 1912 the average monthly yield had fallen to about 20 barrels, partly the result of natural declines, partly owing to deterioration of plant, and partly to inexperience of the new managers. The figures were still smaller in 1914.

The oil is treated in a small, crude refinery, the resulting kerosene being distributed through the province by mule train and used for illuminating purposes.

CHARACTER OF THE SHENSI PETROLEUM

The Yenchang oil varies slightly in character in the different wells, and is dark green in color, has a sweet odor, and a gravity of about 37. The cold test gives a melting-point of about 40° F. The oil has a paraffin base.

TABLE IV

ANALYSES OF YENCHANG OILS

	Well 1	Well 2	Well 5	Yenchang Oil	Yenchang Oil
Analyst	Clapp	Clapp	Clapp	Taylor	Inami
Gravity, Be	36.5	37.5	38.1		37.5
Flash point (degrees)	104	77.5	60		
Burning point (degrees)	108	90	60		
Gasoline, benzine, etc. (per cent)	10.5	11.0	13.6	27.5	53.5
Kerosene (per cent)	25.0	27.5	26.0	12.5	
Light Lub. oil (per cent) / Heavy Lub. oil (per cent)	56.0	55.0	52.0	25	46.5
Paraffin (per cent) / Residue (per cent)	8.5	6.5	8.4	35	

Besides a number of partial examinations by Chinese, tests of the Yenchang oil have been made by K. Inami, Chinese examining engineer, Prof. J. G. Taylor of the Anglo-Chinese College in Tientsin, and F. G. Clapp.

In the Clapp tests, products distilled up to 302° F. are classed

as gasoline, from 302° F. to 554° F. as kerosene, and over 554° F. as lubricating oils. The limits adopted by Taylor and Inami are not known, but are evidently quite different. The increased recovery resulting from improved methods has led to the use of the higher temperature limits adopted by Clapp.

DETAILED TEST OF OIL FROM WELL 5

A sample collected by drillers, November, 1914; tested by F. G. Clapp, Nov. 28, 1914; color, dark green; odor, slight; gravity (corrected to 60° F.), 38.15; flash point, 57; fire point, 58; flash point

TABLE V

DISTILLATION TESTS

c.c.	Per Cent	Temperature		Gravity (Observed)	Temperature at Which Observed	Gravity (Corrected to 60° Temp.)
		Start	Off			
16.....	6.4	130	250	66.5	59	66.6
18.....	7.2	250	302	58.25	61	58.15
65.....	28.0	302	554	45.75	63	45.45
10.....	4.0	554	600	Too little to test gravity		
25.....	10.0	600	650	34.38		
25.....	10.0	650	700	About 40	64	
25.....	10.0	700	700	Becomes solid		
25.....	10.0	700	700	36.0	75	34.9
20.....	8.0	700	700	35.0	77	33.7

(second trial), 59; fire point (second trial), 60; barometric pressure at time of test, 27.55 inches; approximate attitude of well, 2,550 feet; test made at same altitude; air-temperature during test, about 55 degrees (variable) indoors; depth to oil, 170 feet (more or less). Reported as from same horizon as in well No. 1; well located 625 feet S. 60° W. from No. 1; difference in elevation, estimated 30 feet; cold test, oil melts at 42° F.; amount of oil tested, 250 c.c.; paraffin, very much; asphalt, none detected; color by transmitted light, amber brown.

Tested with 200 c.c. gasoline, let stand until next day. No results.

OIL PROSPECTS

Unfavorable factors.—The principal unfavorable factors in the Shensi basin may be outlined as follows:

1. The Shan-si coal-bearing series (Pennsylvanian and Permian) which alone carries sufficient organic matter to afford an adequate source of petroleum

in large quantities, is not only of limited thickness (500–1,000 feet) but lies at great depths (4,000 feet or more) in those parts of the province where the disturbance is not too great to make the occurrence of oil unlikely.

2. The Pu-hsien series (Fig. 5) underlying the Shen-si series, although within reach of the drill in many places, consists of 1,500–2,000 feet of sandstones and shale of a character which makes the occurrence of oil unlikely.
3. The Shen-si series, 6,000 feet thick, is chiefly a hard, gray cross-bedded shaly sandstone (Figs. 6–7). Although there are thin local streaks of limestone, a few coals, and in places thin beds of shale, the outstanding characteristic of the series is its almost uniformly sandy character. Organic matter capable of affording large volumes of oil has apparently been lacking and cap-rocks are absent throughout vast areas. The general tendency in rocks of such uniformly sandy character must be toward the dissemination rather than concentration of such oil as may be present.
4. In the parts of Shensi where the metamorphism, as indicated by carbon ratios, is not prohibitive to the occurrence of oil in large quantities, the structures are generally weak and unsatisfactory.
5. The regional structure is synclinal, with the slopes broken only by relatively weak terraces and very rarely by slight and strictly local reversals of dip. There is little in the structure to cause concentration of oil in pools.
6. The Shen-si beds for the most part represent continental deposition, and are of an age in which the general climatic conditions seldom favored the formation of oil.

Favorable factors.—The favorable factors as regards the possible presence of oil in Shensi are given as follows:

1. Oil is unquestionably present in the Shensi series, as shown by 63 known seepages and the production of the two Yenchang wells.
2. The production of Yenchang, coming from 200 feet, was apparently from what may be called "stray" oil, or oil in bedding planes within the limits of meteoric circulation and in the process of escaping. If a production of 60 barrels a day was obtainable under such conditions, larger supplies should be found under normal reservoir and cover conditions.
3. Occasional beds like the thick sandstone near Yenanfu are of considerable extent, and sandy lenses are possible at almost any point. Both are capable of forming excellent reservoirs.
4. Denser layers of sandstone and thin limestones may form retaining covers when shales are absent.
5. Notwithstanding the apparent absence of organic matter of a type likely to afford oil, the seepages show that at least small quantities of petroleum are actually present at localities broadly scattered over most of the outcrop of the Shen-si series.
6. The carbon ratios are apparently favorable to the occurrence of oil beyond a distance of a few miles from the basin rim.

7. The Shensi formation, although of Jurassic age and to all appearances mainly of continental origin, contains coals, thin limestone lenses, and a few thin shales. No red beds are present.

Conclusions.—In view of the geology, productive wells, and widely disseminated seepages, the writers believe that a definite possibility of the production of petroleum on a commercial scale exists. In their original reports, however, they recognized that the local structures are small, weak, and often absent over broad areas, and that great persistence and probably the drilling of a large number of dry holes would be necessary to develop the field. It was even a question whether locations based on geologic evidence alone would be successful.

The results of drilling, both by Chinese and Americans, tend to confirm their opinion that while there is a possibility of a considerable number of pools in Shensi, the province is not likely to be an enormous producer, and the field will probably be very spotted and the proportion of gushers small. Whether the oil can be developed economically on a large scale is uncertain. It is only by having a large number of wells pumped in one or adjoining fields and the oil transported efficiently and economically that such wells will pay, and a possibility exists that even then the amount of oil recoverable may be too small for profitable operations.

The writers were instructed to recommend six areas for drilling, and after most careful leveling, plane-table surveys, and the construction of topographic contour and geologic structure maps of areas selected from the reconnaissance traverses, the following areas were specified: (1) Yenchang, (2) Yungpingchên, (3) Yenanfu, and (4) Tientou. A second Tientou area and one near Tungkuan were chosen by our associates after the return of the writers to America. The natures of the structures have been indicated in connection with the descriptions of the wells. None of them were at all satisfactory from the geologic standpoint, but were the best that could be found in a region of nearly uniform westerly or northwesterly dip.

Summary.—The northern part of Shensi is, within limitations, potential oil territory, but structural and stratigraphic indications that might guide drilling are few, hence pools will be located, if at all, only at the expense of many dry holes. The production of indi-

vidual wells and pools will probably be small but may be important collectively, although prolific production is unlikely. Since all equipment and supplies must be brought in carts over the 300 to 400 miles of soft loess roads, transportation costs are likely to make operations unprofitable unless a sufficient number of pools are developed to warrant the construction of railways or pipe lines.

OIL PROSPECTS IN KANSU

INTRODUCTION

Occasional seepages have been reported both in the east and extreme west, but except that part within the limits of the Shensi basin, the province was not examined by the writers.

GEOLOGY

The eastern portion of Kansu lies within the Shensi basin. According to the meager data available, the central part of the province is characterized by a series of anticlinal structures running N. 50°–60° W. and involving Carboniferous, Cambro-Ordovician, and ancient metamorphic rocks, associated with igneous areas of considerable extent, alternating with basins in which Jurassic or later formations may occur. The great northwestern arm of the province appears to lie mainly in a synclinorium, designated the West Kansu basin containing coal-bearing rocks from which seepages are reported. The basin may or may not connect geologically or geographically with the North Sinkiang basin on the northwest, in which, it is reported, important oil seepages occur.

The formations in the Kansu section of the North Shensi Basin and the probable structure at the western rim have been described under "Geology of Shensi."

METAMORPHISM

It is improbable that the formations of the North Shensi basin lying within the province of Kansu have anywhere been metamorphosed to an extent that will preclude the occurrence of oil in commercial quantities, but the reverse is true of the graben belt outside the rim of the basin proper. Of the conditions in the West Kansu basin no information is available.

SEEPAGES

East Kansu.—No oil showings were noticed by the writers, but a seepage of what was described as dark amber oil was reported by a soldier, who claimed personally to have seen it collected and burned in native lamps, as occurring near Yuenningshen, 110 mile southwest of Tachonyuen on the trail to Pingliangfu. It is said to be well known locally and not difficult to find.

West Kansu.—Reports of seepages, though somewhat vague, are persistent. Engler and Hoeffer[1] give the following details:

> On the south of the Gobi desert, at the base of the Nanchang Mountains in the province of Kansu, at a distance of 20 miles south of Shangtekingpu, near the river Tsche Kingsia, are situated petroleum rocks. About a dozen wells, 3 feet deep, are found in enclosures. . . . . Four families, descendants of the discoverers, have authorization for collecting the oil, which daily accumulates on the surface of the water. Out of the total quantity of petroleum they have to pay the state 500 gallons, and contribute to the illumination of the pagodas 100 gallons a year; the rest is their exclusive property. . . . . The oil is used as lubricating oil, or, after it has been submitted to a partial cleaning, as an illuminant. (Translation.)

The seepages attributed by Redwood to Kansu seem to be actually located in Sinkiang, with the exception of that at the foot of the Nan Shan, which may be the same as that described by Engler and Hoeffer. It is reported that a resident of Tientsin had (1914) a concession for the development of oil at this or another seepage in the vicinity. The Chinese Oil Administration reports a seepage near Tunghuanghsien, 40 miles from the farther end of the "pan-handle" of Kansu.

OIL PROSPECTS

East Kansu.—Except for a narrow belt along the Shensi line, the top of the Shen-si series seems to lie at a depth between 3,000 and 5,000 feet; hence it is not attractive as a source of oil. The thin (200 feet) transition zone of red shales and limestone, with sandstone and conglomerate toward the south, the great massive false-bedded sandstone (2,000 feet) and the regularly bedded reddish sandstone (1,000 feet) overlying the Shen-si beds in the order given, are not of a character to make the occurrence of oil likely. The green and red shales, which form the surface throughout the greater portion of the basin in

[1] *Das Erdol* Vol. 2, p. 475, 1911.

east Kansu probably contain some oil, but it is not believed to be present in quantities sufficient to warrant any attempt at development at this time.

West Kansu.—Reports indicate a chance of petroleum production in this region, but the possibilities are as yet unconfirmed. The distance from transportation routes will make the development of oil impracticable for anything but local use until such time as railways shall be constructed into the province, either as the result of political or general commercial considerations, or following the unlikely event of the discovery of a highly prolific oil field.

COMPARISON OF NORTHEASTERN CHINA AND AMERICAN OIL FIELDS

A few words of comparison of the oil fields of northeastern China with those of America may not be out of place. The general similarity of arrangement of coastal plain, piedmont, mountain, and basin belts of the part of China under consideration to those of the northeastern United States has been pointed out in the section on Geologic provinces, under Geology.

There are, however, certain striking points of dissimilarity. Instead of relatively open folds, practically without faulting, as in the Alleghenies, the flexures of northeastern China are sharp and associated with profound faulting, giving a succession of horsts and grabens rather than long simple anticlines and synclines such as characterize the western Pennsylvania, eastern West Virginia, and Ohio regions.

Paleozoic limestones are found in both countries, but the metamorphism is far more advanced in China than in America. The Devonian, the thick shales of which, rich in organic matter, have yielded such liberal quantities of petroleum in America, are absent in northeastern China, and the Carboniferous, including the Permian, is inconsequential in thickness, seldom exceeding 500 feet. Northeastern China is, therefore, without great Paleozoic sources of oil such as have yielded the bulk of the great production of the Eastern and Mid-continental fields. Even the limited thickness of possible petroliferous beds of this age quickly sink to depths beyond the limit of practicable drilling.

The Paleozoic beds in China are followed by thick and unpromising Triassic sandstones, in turn overlain by thousands of feet of Jurassic sandstones and shales. Although, as shown by a few calcareous beds with marine fossils and limited amounts of salt water, marine conditions prevailed at times, the post-Carboniferous beds as a whole are predominantly continental in origin, the accumulation taking place in an embayment apparently shut off, except at long intervals, from the sea. Coals are rare, and shales carrying sufficient organic matter to afford oil in large quantities are almost entirely lacking. Adequate cap-rocks are few and the prevailingly sandy character of the beds favors dissemination rather than segregation of oil. Strong anticlines, domes, and terraces, such as are so prevalent in the most productive parts of the Eastern and Mid-continental fields in the United States, are absent in the principal basin of northeastern China, where the structures are weak, suggesting those of the Clinton sand of central Ohio.

Metamorphism is also more advanced in the China than in the American fields, the carbon ratios even in the Jurassic beds being high, if not prohibitive, at the rim of the basin, where alone the structures are markedly favorable.

In the United States and Canada, much of the Cretaceous is marine and rich in organic matter. In the basin region of China, it appears to be limited to local sub-loess gravels of sub-aerial origin, which are practically destitute of organic matter of any sort.

Too little is known of the coastal plain to warrant definite comparisons, but so far as is known, there is nothing comparable with the petroliferous formations of the Cretaceous in the Mississippi Embayment and the Gulf Coastal Plain.

OIL PROSPECTS OF THE DESERT BASIN OF WESTERN AUSTRALIA[1]

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ABSTRACT

Seven sedimentary artesian basins are, in whole or in part, situated within the great state of Western Australia which covers an area about one-third the size of the United States. The largest of these is Desert Basin, comprising an area approximately 450 miles long and 325 miles wide, with a population of only about 3,000 persons. The formations of Desert Basin range in age from Carboniferous to Tertiary, and by far the most important is a mass of Permo-Carboniferous sandstone thousands of feet in thickness. No impervious capping is known and no positive evidence of seepages could be found in the area covered. Dips are high in the border areas and practically flat in the central areas; but, aside from the structure, no favorable fundamental conditions are known. The basin is believed to be unfavorable for oil.

INTRODUCTION

For some years past the leading Australian newspapers and technical journals have contained references to "The Search for Oil." The subject has engrossed the attention of all classes in the island continent, so that one might almost say that its well-educated inhabitants are divided into two classes—those who believe that Australia contains oil and those who do not.

In the latter part of 1923 the oil controversy had reached a stage where thousands of artesian wells sunk at widely separated points had failed to find oil, and only a few of them had encountered some tens of thousand cubic feet of gas per day; and, in addition, a few widely scattered oil test wells from a few hundred to 4,000 feet deep had failed to find more than a few drops of petroleum. Exceptions to this statement are perhaps a couple of wells in eastern New South Wales and the Roma bore in southern Queensland, where several million cubic feet of gas per day were encountered at great depths and when tested were found to contain a minute quantity of gasoline.

[1] Prepared for presentation before the New York Meeting of the Association, November, 1926.

[2] Consulting geologist, 50 Church Street, New York City.

Keen-visioned business men and geologists of Australia were not satisfied, either with the quality of the negative evidence or with the lack of knowledge concerning the great basin areas of Triassic and Permo-Carboniferous ages from which certain apparently favorable reports had originated. These men realized—what the great public and press did not—that Australia had never been properly investigated for oil, even in a reconnoissance way.

In a country as large as the United States, which had never been studied by men familiar with oil fields, and none of whose brilliant geologists professed any familiarity with oil geology, it was not to be expected that existing opinions would be of great value. Thus reasoned Albert Edward Broué, of Sydney, who had determined to find oil if it existed and who, late in 1923, engaged the writer to proceed to Western Australia for an intensive study of the oil question in the Desert and Northwest basins, where Mr. Broué had options covering hundreds of thousands of square miles. Mr. Broué was later joined in the venture by Mr. Thomas Baker, of Melbourne, who purchased an interest in the Western Australian venture. The investigations of the writer were made under instructions from Mr. Broué, and the results are published with his permission. The writer wishes to express his thanks to Professor Sir T. W. Edgeworth David, the senior Australian geologist; and to Messrs. E. C. Andrews, government geologist of New South Wales; A. Gibb Maitland, government geologist of Western Australia; Leo Jones of Sydney; and other persons for advice and assistance rendered in many ways.

GEOGRAPHY AND GEOLOGY OF WESTERN AUSTRALIA

The state of Western Australia embraces 975,920 square miles, or about one-third the area of the United States. It extends from 14° to 35° S. Lat., and its climate ranges from tropical to temperate. The rainfall varies from more than 40 inches per annum on the southwest coast to more than 30 inches per annum in a part of the extreme north, but throughout about 60 per cent of the state it averages only about 10 inches and in some years is considerably drier.

Physiographically the state has previously been divided into (1)

coastal plains, (2) hill ranges, and (3) interior plateaus, as will be understood by reading a physiographic outline of the state by Jutson.[1] The rocks range in age from Archean to Recent, as described

FIG. 1 Map of Western Australia, showing location of sedimentary basins

[1] J. T. Jutson, *W. A. Geol. Survey Bull.*, Vol. 61 (1914), 229 pp., 119 figs., 3 plates.

in a rather complete treatise on general geology by Gibb Maitland,[1] the government geologist, from whom certain details stated herein are taken and by whom a bibliography of the geology of the state is also supplied.[2] The geologic relations to the other states of the Commonwealth have been discussed by David.[3]

Two-thirds of the state, including the major part of the central areas, consists of igneous and greatly metamorphosed and altered complex—to describe all of which would be to embark on a lengthy geologic study, with every prospect that the areal extent, age, and

TABLE I

ARTESIAN BASINS OF WESTERN AUSTRALIA

Names	Approx. Area Square Miles
Desert	125,000
Eucla	100,000*
Northwest Coastal Plain	40,000
Gulf	5,000*
Ord River	3,000*

* Including the part of the basin situated outside Western Australia.

relations of many formations would remain inexplicable. Let the statement suffice that these ancient rocks occupy the immense central areas and touch the coast over vast distances, but that they are bordered and indented in places by artesian basins, of which the six areas (Fig. 1) mentioned in Table I are commonly recognized.

A large part of the surface of Desert, Northwest, Coastal Plain, and Gulf basins consists of Permo-Carboniferous strata; that of Eucla Basin is Cretaceous and Tertiary, and that of Ord River Basin is Cambrian. Other minor Carboniferous and later areas exist, for example, (1) the Collie coal field in southwestern Western Australia and (2) an inland Tertiary area in the upper Fortesque River Valley, but these are unimportant.

[1] A. Gibb Maitland, "A Summary of the Geology of Western Australia," *The Mining Handbook, W. A. Geol. Survey Mem. No. 1*, chap. i (1919), 55 pp., 1 map, 80 figs.

[2] *W. A. Geol. Survey Bull. 1*, 1898, 31 pp.

[3] Sir T. W. Edgeworth David, "The Geology of the Commonwealth," *Federal Handbook* prepared in connection with the Eighty-fourth Meeting of the British Association for the Advancement of Science, 1914, pp. 241–325, 8 illus.

When it is said that the population of Western Australia is only 332,000 persons, of whom 155,000 live in Perth, the capital city, it will be understood that not much may be known of the geologic or geographic details of vast regions. The white population of the north half of the state is limited to a few thousand.

GENERAL DESCRIPTION OF DESERT BASIN

The total population of Desert Basin is limited to about 3,000 persons (a few hundred whites and the balance Asiatics and aborigines) in Broome on the Indian Ocean; a few score of whites in Derby, the Fitzroy River Valley, and a belt 10 miles wide fringing the ocean; with possibly 2,000 savage aborigines in the desolate and largely unexplored area. There are no settlements except those of Broome and Derby. The Geological Survey of Western Australia, through its government geologist, Mr. Gibb Maitland, and his staff, has done remarkable work under great difficulties with insufficient funds, but the state is too vast to permit of its geology being deciphered by a few men only.

The largest artesian basin in the state lies in the southern part of Kimberley and northern part of Eastern Division, extending into the northeastern corner of Northwest Division. Desert Basin is roughly quadrilateral in shape, with its long dimension of 450 miles at approximately right angles to the coast, and its breadth of 325 miles extending northeast and southwest (Fig. 2). About 80 per cent of this area lies inside a vast barren sand-ridge country known as the "Great Sandy Desert," or sometimes the "Kimberley Desert." Only one road traverses the basin from north to south along the coast.

The Desert Basin is a topographic as well as a stratigraphic unit, bounded on the north by a vertical sandstone escarpment which depresses the surface in that direction by several hundred feet. The escarpment extends east from a point 77 miles southeast of Broome, winding in and out from canyon to canyon and finally losing itself in a maze of table-lands 200 miles farther east.

PREVIOUS INVESTIGATIONS

Little geologic work has been done in this desert. Talbot,[1] while

[1] H. W. B. Talbot, "Geological Observations in the Country between Wiluna, Hall's Creek, and Tanami," *W. A. Geol. Survey Bull. 39*, 1910, 88 pp., 3 maps, 44 figs.

engaged in a survey of the Canning Stock Route, crossed the desert in a southeasterly direction from Lat. 23°, Long. 122° 30′. Leo Jones also traversed this route, but no report has been published on his

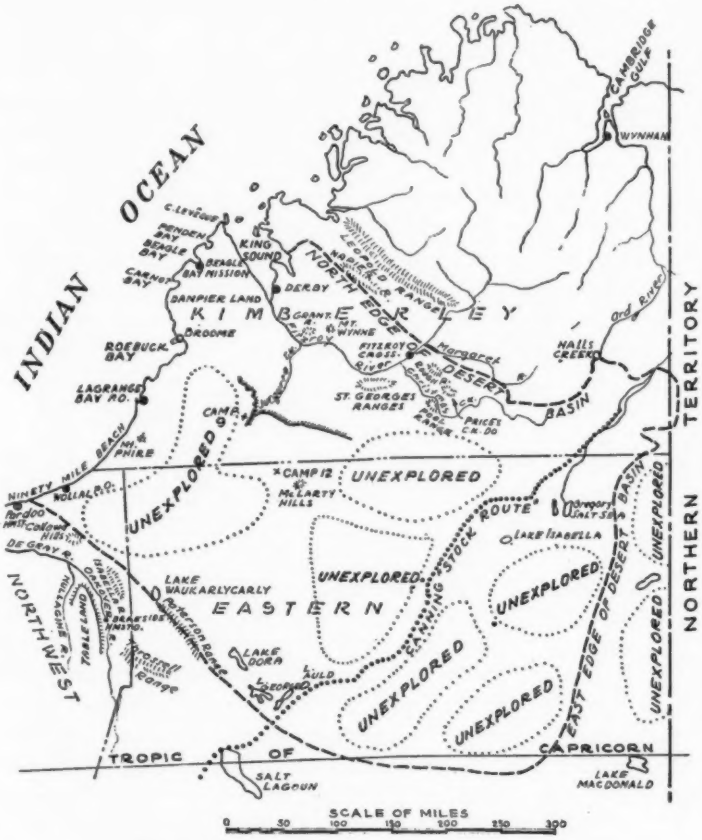

FIG. 2.—Map of Desert Basin of Western Australia

observations. The expedition met with disaster, being attacked by aborigines at night; one man was murdered and the leader of the party injured, so that geologic work must have been greatly hampered. A later report by Talbot gives some information concerning

a bit of the southwest border of the basin[1] in the vicinity of Throssel and Paterson ranges. The desert itself is only known to have been traversed half a dozen times, by the two geologists previously mentioned and by the intrepid explorers Col. Warburton (1873), Hon. D. A. Carnegie (1896–97), R. J. Ankatell (1906), and the Calvert Expedition (1896–97). Practically every party crossing the desert has met with some fatal disaster.

Only in the northern edge of the basin has any important previous geologic work been done, for the valley of Fitzroy River is accessible by horse and automobile during the winter, or dry season, from Derby on King Sound to Hall's Creek in Lat. 18° 15′, Long. 128°. The original geologic investigations in this area were made by Hardman,[2] but a good summary report was later given by Jack,[3] and its oil possibilities have recently been summarized by Wade.[4] Reports also have been made by Talbot and Blatchford for certain oil interests; but the present writer is unable to agree with the optimism expressed by them.

NORTH ESCARPMENT OF THE INTERIOR PLATEAU

The north escarpment of the interior plateau constitutes a vast geographic feature. Commencing 35 miles southeast of Hamilton's well, which is 42 miles from Broome, the escarpment first appears merely as a breaking away of the coastal type of country known as the "pindan sands," which extends to that point from the inner edge of the sea-level plains near Broome. The pindan sands, covered with a thick growth of many varieties of trees and shrubs, rise from sea-level to a height of about 200 feet at Hamilton's well and to about 700 feet at the "breakaways" mentioned. A few low hills in the vicinity rise a few feet higher; hence the name "ranges" by which they are known to inhabitants of Kimberley Division.

[1] "The Geology and Mineral Resources of the Northwest, Central, and Eastern Divisions between Long. 119° and 122° E. and Lat. 22° and 28° S.," *W. A. Geol. Survey Bull. 83*, 1920, 226 pp., 1 map, 55 figs., and an atlas of 15 plates.

[2] E. T. Hardman, *Report on the Geology of the Kimberley District*. Perth, printed by authority, 1884 and again in 1885.

[3] R. Logan Jack, "The Prospects of Obtaining Artesian Water in the Kimberley District," *W. A. Geol. Survey Bull. 25*, 1906, 46 pp. and geol. map.

[4] Arthur Wade, *Petroleum Prospects, Kimberley District of Western Australia and Northern Territory*. Melbourne, by order of the Senate, October 8, 1924, pp. 10–26.

The only claim of the north escarpment to the designation "ranges" consists, first, in a slight steepening in northeastward rise of the plateau along a line where the "Desert sandstones" rise from beneath plains adjoining to the west and south, and secondly, in the erosional dissection of the sandstone itself, where it drops abruptly 100 to 300 feet into canyons, or "breakaways," tributary to the broad valley which descends slightly northward and constitutes part of the Fitzroy lowland. A generalized section across Desert Basin is shown in Figure 3, from which the formations are seen to dip 1°–2° SW.; hence the escarpment is typical of those the world over on up-

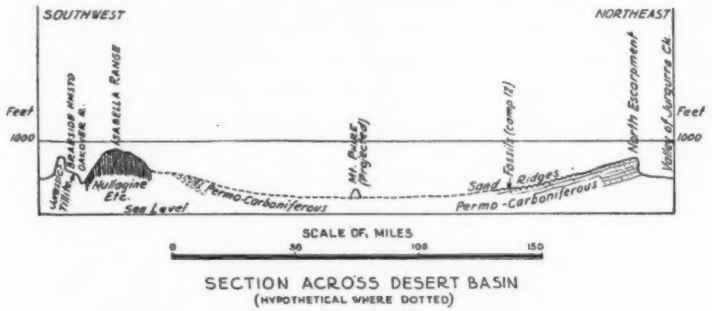

FIG. 3.—Section across Desert Basin

dip flanks of structure in which sandstone is conspicuous. Calculations based on observed dips in the escarpment, on the coast and in Mount Phire (see later), lead to the opinion that the escarpment strata and higher beds may be as much as 10,000 feet in thickness.

Although the Fitzroy Valley northeast of the point, 77 miles southeast from Broome, where the escarpment is touched by the writer's motor road from Broome to the desert, can be reached by an easy grade of not more than 100 feet in a mile, and although the crest of the plateau is accessible on its west side by an even more imperceptible grade, the valley descends eastward and the ranges rise gradually southeastward, so that within a mile of the northwest termination of the escarpment the plateau is nearly 100 feet above the valley and a few miles farther southeast the relief is 200 feet or more.

Many isolated table-lands with flat summits, from a few acres to several hundred acres in extent, stand in the valley and are higher than the main plateau only by an amount equal to the normal rise in dip toward the northeast (several score feet in a mile). Maps of the Lands Department show several of these outliers, for example, Goorda Tower, Babrongan Tower, Mount Alexander, and Mount Jarlemai, far to the northeast; and some of these were visible in the distance from points visited on the escarpment.

The rocks of the north escarpment are fine-grained white sandstones, somewhat aluminous but never calcareous or even approaching the consistency of shale. In places they contain ferruginous concretions. The attitude of the rocks ranges from flat to a dip of 2° SW. In a few localities, as at the head of a deep "breakaway" at Camp 9, 130 miles southeast of Broome, areas as large as 3 miles in length and a few hundred feet in width, capping the plateau a short distance back from the escarpment, were seen to be composed of hard, light-gray to white quartzite. This rock is only a few feet thick and takes the place of limonitic laterite which is an almost constant feature of any sandstone outcrop in the semi-desert areas. Aerial and other observers report a great ledge of gray quartzite extending from a point on the Derby road, about 60 miles northeast of Broome, north to the vicinity of Cape Levêque; and this last-mentioned quartzite may constitute part of the same series of rocks. Such quartzite is frequently only a vitrified phase of the surface-hardened sandstones and is common in rocks of all ages throughout tropical Australia.

The escarpment is not simple in contour, but extends southeast many miles from its north extremity, then turns east, forming an irregular line of cliffs—vertical and inaccessible to a vehicle at any point, rarely scalable by man, and the crest attainable by horses only at points dozens of miles apart. The escarpment extends east approximately 200 miles and probably merges with certain table-lands described by Carnegie and others in the vicinity of Canning Stock Route. A remarkable circumstance is the absence of surface drainage in the desert area 400 miles long and 200 miles wide which constitutes the major part of the geologic basin.

NATURE OF THE DESERT

South of the escarpment the main feature is a vast complex of parallel and rather barren sand ridges trending east and west, interspersed with a few hills, table-lands, and rock outcrops and devoid of water except for occasional rock holes and "native soaks." The region is predominantly rough and sandy, but its seaward belt, a hundred miles or more in width, consists largely of thick pindan (low native bush) or brush. The center cannot be reached by any known means except camel or aeroplane. By diligent effort the party headed by the writer succeeded in driving three motor tractors to the top of the escarpment by way of its western, gently-rising termination; then it traveled with one of the machines at right angles to the trend of the sand ridges to a point 185 miles southeast of Broome. If the desert can be further invaded by car it will be by traveling parallel to these ridges directly inland from Ninety-Mile Beach, with an engine consuming a minimum of gasoline and water such as has never been taken to that region.

STRATIGRAPHY

The strata of Desert Basin seem to consist of more than 12,000 feet of Carboniferous, Permo-Carboniferous, and Jurassic sediments, unconformably overlying Nullagine, Cambrian, and possibly Devonian beds. At, or near, the base of the Carboniferous are perhaps 800 to 1,000 feet of impure red goniatite limestones and massive coral limestones. These rocks and thick interstratified sandy beds are known in literature as the "Lower Series" of Carboniferous and Permo-Carboniferous ages, overlain by that known to all investigators to date as the "Upper Series."

Within a few score feet of the base of this Upper Series lies a 30-foot tillite bed (perhaps the Kimberley representative of the Lyons conglomerate of Northwest Basin) in which large and numerous striated boulders have been found at several places in Fitzroy Valley. Above the tillite lie at least 4,000 feet of massive or flaggy white and gray sandstones, mainly quartzose and unfossiliferous, but containing several fossiliferous horizons. So far as observed by the writer, all shales and limestones in this series are thin and

unimportant; although shales possibly 50 feet thick are reported in the northeastern part of the basin. There is no doubt that this Upper Series is of Permo-Carboniferous age, for numerous fossil species have been collected in it and identified by the government geologists.

FOSSIL COLLECTIONS AND THEIR SIGNIFICANCE

A point needing further attention is the abundant occurrence of large pectenoid valves and others resembling *Productus* in ferruginous conglomeratic sandstones of hematitic hardness between 83d and 87th sand ridges in the semi-desert area about 185 miles by tractor southeast of Broome, counting from the north, and estimated only a few miles west of McLarty Hills as mapped. No outcrops exist between here and the north escarpment, but those mentioned are plentiful throughout several square miles at an elevation about 300 feet barometrically above sea-level. The fossils were examined by Mr. W. S. Dun, of Sydney, through the agency of Professor Sir T. W. Edgeworth David and the courtesy of Mr. E. C. Andrews, government geologist of New South Wales, and were found not definitely determinable but of probable Permo-Carboniferous age. They include species of the genera *Spirifera, Athyris, Strophalosia, Stenopora, Chonetes,* and many others, and the species are enumerated in a paper by the writer.[1]

About 50 miles south of Fitzroy River and bounding the Great Plateau of Western Australia on its north side is the sandstone[2] escarpment already mentioned. Judging by dips prevalent in this escarpment the total thickness of the Upper Series may be as much as 10,000 feet, instead of 4,000 feet as previously assumed.

PROBABLE PERMO-CARBONIFEROUS ROCKS OF DAMPIER LAND

Although the western edge of the peninsula (once known as Dampier Land and comprising Dampier's "Miserablest Country") west of King Sound is Jurassic as mapped, the balance of the pen-

[1] "A Few Observations on the Geology and Geography of Northwest and Desert Basins, Western Australia," *Proc. Linnean Soc., N. S. W.*, Vol. 50, Part 2 (1925), pp. 54–55.

[2] The term "Desert sandstones" is unavailable, having been used far and wide throughout Australia and apparently misapplied to strata of Carboniferous, Permo-Carboniferous, and Cretaceous-Tertiary age.

insula may be largely of an age similar to that of the north escarpment of the plateau. The impression of the writer is that the strata in the central parts of Dampier Land are of duller shades than the Jurassic which forms the coast. The elevation of the central hills, several hundred feet above sea-level, together with certain structural evidences, gives an impression that they may constitute a fold against which Jurassic sediments were deposited to the west and southwest. A coarse ferruginous conglomeratic sandstone which forms Kings Peaks (low hills on the coast between Carnot and Beagle Bay about 60 miles due north of Broome) has a peculiar red glaze and hematitic veining, and its appearance suggests the Permo-Carboniferous beds 185 miles in the interior behind Ninety-Mile Beach. Similar hard, coarse, red ferruginous sandstones extend from Kings Peaks to Beagle and Pender bays.

ROCKS OF JURASSIC AGE

The published geologic map shows a Jurassic area in western Desert Basin, including a small patch near Derby, nearly the whole of the peninsula west of King Sound, and a belt along the coast with a breadth of 40 miles near Broome diminishing to nothing at Wollal. Certain siliceous laterite and in many places quartz- or flint-capped remnants along and within a few miles of the coast, apparently contemporaneous with beds which descend at least 1,800 feet below sea-level in a Broome artesian well, are probably Jurassic, largely because of the presence of *Belemnites* in that well. Doubtless an unconformity exists between Permo-Carboniferous and Jurassic strata, but it has not been proved; moreover, it is not yet known whether Jurassic rocks are limited to less than 2,000 feet or are many thousands of feet thick. So far as lithologic character is concerned these beds are not greatly different from the Permo-Carboniferous beds of the plateau escarpment, a fact which suggests that these sediments may form a continuous series, although the disparity in age renders such an interrupted cycle of deposition unlikely.

Gibb Maitland suggested[1] that Jurassic rocks "may extend some distance into the interior" east of Ninety-Mile Beach. The Jurassics are not continuous, nevertheless, for fossils, probable Permo-

[1] *Op. cit.*, p. 41.

Carboniferous, have been found in characteristically glazed, red, conglomeratic sandstone at Anna Plains Station. This rock occurs in many places northward to Lagrange and beyond, and Permo-Carboniferous fossils occur plentifully in similar rock west of the mapped position of McLarty Hills.

The identification of Jurassic strata in western Desert Basin is dependent on the discovery by Gibb Maitland of *Belemnites* in artesian well No. 2 at Broome. The mapped extension of the Jurassics north and south from Broome is doubtless based largely on the occurrence of certain outcrops—similar to those at Gantheaume Point and Entrance Point near Broome—along the coast at widely separated localities from Cape Borda, 100 miles north of Broome, to Cape Villaret, 25 miles southwest of the same town. The predominant rocks at these localities are fine-grained, cross-bedded, white, quartz sandstones in which small flakes of mica are conspicuous. Mica flakes were not noticed in known Permo-Carboniferous rocks, but they may exist.

Cape Villaret is the last coastal outcrop to the south at which probable Jurassic material was seen, but Mount Phire, 16 miles from the coast and 50 miles south of Lagrange Bay, was found to be an unmapped table-top group of five hills distributed over an area of more than 2 square miles. The Mount Phire group is estimated 100 to 300 feet above the sea-level plains. The hills as usual are capped by laterite. Owing to a roughly regular height of table-tops (Gantheaume Point, Capes Borda and Villaret, Mount Phire, and Callawa Hills) 70 to 130 feet above outcrops, and to the presence of these practically flat-lying rocks within a few miles of the Broome artesian well in which Jurassic fossils were found, the rocks are probably of Jurassic age. Other outliers may be dotted over the southwest part of Desert Basin but are as yet undiscovered.

TERTIARY AND POST-TERTIARY STRATA

The Tertiary strata of Kimberley Division have received little attention. A careful study of the narrow coastal belt mapped as Tertiary and post-Tertiary between Roeburne and Broome might lead to interesting differentiations. Some outcrops of low-lying limestones and calcareous sandstones along the coast are undoubtedly

Quaternary and Recent. Observations of the writer include the following:

1. Unconsolidated sand dunes and sand ridges constitute the most recent formation in Western Australia and are still being deposited, not only on the coast but also over large areas in the interior. In traversing south from the North Escarpment eighty-five of these great sand ridges were crossed, each constituting an entity, being straight and persistent and few of them having visible termination. Most of the ridges are covered with a growth of hummocky spinifex, but they have a greater proportion of sand than spinifex and support a few trees, as do also the valleys between them. The sand ridges are not only present in the interior, but strike the coast throughout a belt roughly 70 miles wide between Wollal and Pardoo Homesteads and render motor travel difficult along the main north-south road.

2. Raised sea beaches in the nature of sandstone, limestone, and comminuted masses of shells and sand grains were seen at frequent intervals between Port Hedland and Lagrange, and they sometimes rise 50 feet above tide-level. In topography they take the form of narrow belts some of which parallel the coast for miles. The surface of these beds is frequently hardened and the cross-bedding has a concentric pseudo-folded appearance.

3. Sea-level "marshes," including Roebuck, Anna, and other plains, exist at, or within 3 feet of, the present maximum high-water mark. They are formed of silt, are saliferous and full of recent marine shells which have been identified by Mr. W. S. Dun. The plains have at times a diameter as much as 30 miles inland from the coast, fringed and backed by pindan sands. These sea-level plains appear to be, next to unconsolidated sand dunes and raised beaches, the most recent formation of southern Kimberley Division.

4. Consolidated sand dunes are found. They are not necessarily older in every instance than the unconsolidated sand dunes, yet have the consistency of sandstone. They are in places wave-cut and show vertical sections 10 to 70 feet in height from Broome southward.

5. "Coquina," or shell rock, consisting of shell deposits 20 feet or more in thickness, is found above high-water mark near Port Hedland and Broome.

6. A zone of red soil a few feet in thickness is exposed underneath the consolidated coastal sand dunes at Cape Villaret.

7. Practically all of the country about Broome, with the exception of the sea-level plains and small rock areas, is known as the "pindan sands." These consist of level to gently-sloping unconsolidated sands which rise in places several hundred feet above sea-level a few miles from the coast and in general slope upward against older formations. These sands are probably of different ages, from Permo-Carboniferous to Recent, and cannot be differentiated until enough wells are sunk to find and identify fossils at widespread localities. The pindan sands are generally covered with a thick growth of shrubs or low trees of many varieties, known collectively as "pindan." These sands cover nearly the whole of the peninsula west of King Sound, most of the country north and south of the Broome-Derby road, and extend southeast from the inner edge of Roebuck Plains a distance of more than 100 miles, merging beyond with the sand-ridge country of the semi-desert. They also occupy the spaces between the sand ridges.

GEOLOGIC STRUCTURE

Desert Basin is not merely a topographic and stratigraphic unit, but also a structural one. Dipping southwest from the outcrops and faulted termination of the Permo-Carboniferous in the vicinity of Margaret River, the strata pass under this stream and Fitzroy River and thence to the center of the basin, where they are buried by an immense thickness of sandstones. In the plateau, desert, and central portions no abnormal or reverse dips are known, although outcrops have been observed at many widely separated points.

In the valleys of Fitzroy River and Christmas Creek, however, a number of excellent structures exist, such as would deserve oil-prospecting if other fundamental conditions were in the least favorable. The structures have been mapped in detail by Mr. H. W. B. Talbot and Dr. Torrington Blatchford for Freney Kimberley Oil Company; their descriptions are contained in private reports of these men and in a published report by Wade.[1]

[1] Arthur Wade, *Petroleum Prospects, Kimberley District of Western Australia and Northern Territory*. Melbourne, published by order of the Senate dated October 8, 1924, maps and plates.

The geologic structure of this border region constitutes the only fundamental condition which might be considered favorable from a petroliferous viewpoint, but its importance is minimized by the unfavorable nature of the other fundamentals. Thus a description of geologic structure is mainly of scientific interest. A post-Cambrian movement has displaced the strata of the present Fitzroy Valley along a northwest-southeast line parallel to the bordering mountains, and later movements have folded the Lower and Upper Series of Carboniferous and Permo-Carboniferous ages into angles as high as, or even higher than, Paleozoic strata which commonly yield oil. Reverse dips ranging from 3° to 35° can be seen throughout a distance of 200 miles in the vicinity of the Fitzroy River–Christmas Creek drainage, and they are accompanied by much faulting. Four prominent lines of folding in this valley have been studied and mapped by Blatchford and Talbot and checked by Wade, and these attain the character of domes and anticlines at Mount Wynne, Grant Range, Pool Range, and Price's Creek. The Price's Creek structure is greatly faulted, lies within 10 miles of metamorphic rocks, and the older limestones lie at shallow depth. In addition, the strata along the same belt are intruded by a number of pipe-like masses of leucitite probably of Tertiary age.

RESERVOIR ROCKS, COVER, AND PETROLIFEROUS CONTENT

The question of the porosity of Desert Basin rocks is easily answered, for they consist mainly of sandstone from top to bottom. On the other hand, an absence of cover prevails, for nowhere in explorations of this basin did the writer recognize shale or limestone; the sandstones are mainly soft and porous (except for superficial lateritic silicification or hematitization due to climatic conditions), and only a few feet of shale are reported, near the base of the Permo-Carboniferous Upper Series and hence overlain by thousands of feet of mid-basin sandstones. Although carbonaceous or other organic matter sufficient to have furnished oil may exist in fossiliferous beds of the Lower Series of Carboniferous age, none of the outcropping strata shows any authentic trace of oil.

The only surface "oil indications" ever reported in Desert Basin are at Mount Wynne and Price's Creek. Fine stringers of much-

desiccated bitumen were seen by the writer in specimens of sandstone—possibly semi-metamorphosed—derived from a "wildcat" well drilled at Mount Wynne, 150 miles due east of Broome. Traces of oil were reported by Harry Price, a driller of water wells, from Price's Creek, 260 miles east-southeast of Broome, but have not been definitely confirmed by any one of several geologists who have visited the area in search of the "seepage." Somewhat later, Freney Kimberley Oil Company drilled three tests on Price's Creek dome in Lower Carboniferous limestone" and noted only "traces of oil" at 290 and 490 feet in the No. 1 well and "traces of oil" in the No. 3 well. Not a trace of natural gas or oil was found in any of the artesian bores at Broome and Derby, and no indications of gas have been reported among hundreds of stock wells 30 to 100 feet deep located in the coastal belt 10 miles wide extending from Broome southwest to Port Hedland, an air-line distance of nearly 300 miles.

WELLS DRILLED TO DATE

At Mount Wynne a test well was sunk by Freney Kimberley Oil Company without favorable result, except that Wade reports[1] that

TABLE II

LIST OF EXISTING BORINGS

Description	Date Completed	Depth Feet	Result	Yield* of Water
Broome No. 1	1906	1,459	Water	142,000
Broome No. 2	.....	1,775	Water	?
Lennard Rd., 67 miles from Derby	1910	3,012	Water	140,000
Lennard Rd., 82 miles from Derby	1910	391	Water	Non-flowing
Myall's Well, Derby	1910	900	Water	Flowing
Price's Creek (No. 1)	1922	1,008	Dry	.....
Rough Range (No. 2)	1923	728	Dry	.....
Price's Creek (No. 3)	.....	809	Dry	Non-flowing
Price's Creek (No. 4)	.....	444	Water	Non-flowing
Mount Wynne	1925	1,403+	Water	Plenty

* In gallons per day when allowed to flow uncontrolled.

"globules of oil were noticed in the sludge from 495 feet to 540 feet," and that "a further slight showing of oil was met at 1,309 feet." Within one mile of this spot is a hot sulphurous spring yielding, according to Blatchford, 60,000 to 80,000 gallons an hour of mineral-

[1] *Op. cit.*, p. 22.

ized water at a temperature from 112° to 114° Fahrenheit. The surrounding country is much faulted and dips at angles from 10° to 15°.

Besides the Mount Wynne bore, three "wildcats" at Price's Creek, and one at Rough Range, no tests for oil have been made in Desert Basin. Artesian wells have, however, been sunk in several places. Table II gives what is believed to be a complete list of deep borings made for oil and water.

SUMMARY

The insignificant nature of the oil indications in the several wells drilled, the apparent total absence of natural gas, uncertainty as to actual existence of any surface "indications," lack of shale cover, intense faulting and possible metamorphism of the marginal parts, prohibitive thickness of sandstone throughout enormous areas, and somewhat unsatisfactory source of origin are collectively considered unfavorable to the commercial occurrence of oil in Desert Basin.

OIL PROSPECTS OF THE NORTHWEST BASIN OF WESTERN AUSTRALIA[1]

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ABSTRACT

Northwest Basin is one of seven sedimentary basins situated in whole or in part within the great state of Western Australia which covers an area about one-third the size of the United States. The basin, which has great artesian water flows, is 400 miles long and 175 miles wide, with a population of possibly 2,000 persons, the business of whom is mainly sheep farming. The formations range in age from Carboniferous to Recent, of which by far the most important are Permo-Carboniferous, Mesozoic, and Oligocene strata. Except in the Oligocene the greater part of the stratigraphic section is sandstone. No important impervious cover rocks are known and no positive seepages or other evidences of oil or gas could be found. Dips are high in the Permo-Carboniferous of the eastern marginal area; they decline to low monoclinal dips in the central areas and are again fairly high in certain coastal ranges of Oligocene age. Aside from the structure, however, no favorable fundamental conditions could be found. The basin is believed unfavorable for the existence of oil or gas in commercial quantity.

INTRODUCTION

The oil resources of Western Australia as a whole were discussed in a recent paper[3] and those of Desert Basin specifically are the subject of a paper directly preceding this one. Since each basin forms an entity and they are not contiguous, it was deemed impracticable to attempt to cover them both in a single paper.

The Westralian studies are due to the foresight of Albert Edward Broué of Sydney, who for years had observed Australian oil prospecting, and, acting on the advice of some of the country's eminent geologists, decided to make a complete and scientific examination of the possibilities of certain extensive options which he held in Desert Basin. The original plan for the Westralian field investigations was to cover portions of Desert Basin exclusively. After the work was

[1] Prepared for presentation before the New York Meeting of the Association, November, 1926.

[2] Consulting Geologist, 50 Church Street, New York City.

[3] Frederick G. Clapp, "The Oil Problem of Western Australia," *Econ. Geol.*, Vol. 21, No. 5, pp. 409–30, Aug., 1926.

commenced, however, the client was granted oil options throughout the greater part of Northwest Basin, and an arrangement was subsequently made to examine that region also. The study was made by motor reconnaissance during the months of September and October, 1924.

The writer wishes here to express thanks to Mr. Broué, who personally gave him permission to publish the results, to Professor Sir T. W. Edgeworth David, the senior Australian geologist, for advice and helpfulness, to Messrs. E. C. Andrews, the government geologist of New South Wales, A. Gibb Maitland, the government geologist of Western Australia, W. S. Dun and F. Chapman for paleontological determinations, and to Leo Jones of the same department for the results of a previous investigation.

The reading of this paper should be supplemented by frequent reference to the geologic map of Western Australia,[1] which, with its accompanying report, has been freely referred to by the writer.

GEOGRAPHY AND GEOLOGY OF WESTERN AUSTRALIA

The state of Western Australia embraces 975,920 square miles, or about one-third the area of the United States. It extends from the 14th to the 35th degree of South Latitude and its climate ranges from tropical to temperate. The rainfall is over 30 inches per annum on a bit of the southwestern coast and fully as great in a part of the extreme north, but throughout about sixty per cent of the state it averages only about ten inches and some parts of the state are much drier and are even deserts.

Physiographically the state has previously been subdivided into (1) the Coastal Plain, (2) the Hill Ranges, and (3) the Interior Plateaus, described in a physiographic outline of the state by Jutson.[2] Along the Indian Ocean the Coastal Plain is absent in places between Roeburne and Onslow, but in Gascoyne District of Northwest Division near Carnarvon, its width is 100 miles or more. Both

[1] Maitland, A. Gibb, "A Summary of the Geology of Western Australia," The Mining Handbook, *Geol. Survey Mem.* No. 1, Chapter 1, 1919, 55 pp., 1 map, and 80 figs.

[2] J. T. Jutson, *W. A. Geol. Survey, Bull. 61*, 1914, 229 pp., 119 figs., 3 plates.

the Coastal Plain and Hill Ranges are represented in Northwest Basin.

In order to maintain a consistent basis of discussion, the Coastal Plain has generally been considered practically synonymous with areas of Tertiary strata. Such anomalies exist, however, as the Cape Range, lying between Indian Ocean and Exmouth Gulf, which is of Tertiary age but more than 1,000 feet high, although no other land west of Hill Ranges has an equal elevation. Other inconsistencies in an assumption of the exact coincidence between Coastal Plain and Tertiary areas are that much country which is topographically inside the Coastal Plain is of Mesozoic age and that Kennedy, Carrandibby, and other ranges in the eastern part of Northwest Basin are topographically part of the Interior Plateaus but nevertheless of Permo-Carboniferous age.

The rocks of Western Australia range in age from Archean to Recent, as described in a rather complete treatise on the general geology by Gibb Maitland,[1] the government geologist, from whom many details stated herein are taken, and by whom a bibliography of the geology of the state is also supplied.[2] Geologic relations to other states of the Commonwealth have been discussed by David.[3] Two-thirds of the state, including the major part of the central areas, consists of igneous and greatly metamorphosed and altered Archean, pre-Cambrian, and ancient Paleozoic strata (Nullagine) of great complexity. These ancient areas touch the coast over vast distances, but are bordered and indented in places by artesian basins.

A table of these basins is given in the discussion of Desert Basin, and from Figure 1, accompanying that paper, it will be seen that Northwest Basin ranks third in size, having an area estimated as 32,000 square miles.

A large part of the area of Desert, Northwest, Coastal Plain, and Gulf basins consists of Permo-Carboniferous strata, the area of Eucla Basin is Cretaceous and Tertiary, and Ord River Basin is

[1] *Op. cit.*

[2] *W. A. Geol. Survey, Bull. 1*, 1898, 31 pp.

[3] Sir T. W. Edgeworth David, "The Geology of the Commonwealth," *Federal Handbook of Australia*, prepared in connection with the Eighty-fourth Meeting of the British Association for the Advancement of Science, held in Australia, August, 1914, pp. 241–325, 8 illus.

mainly Cambrian. Minor Carboniferous and later areas exist, as (1) the Collie coal field in southwestern Western Australia and (2) an inland Tertiary area in the upper Fortesque River Valley, 200 miles east of Northwest Basin, but these basins are unimportant.

When it is said that the population of Western Australia consists of only 332,000 persons, of whom 155,000 live in Perth—the capital city—it will be understood that not much may be known of the geologic or geographic details of vast regions. The white population of the north half of the state is limited to a few thousand.

GENERAL DESCRIPTION OF NORTHWEST BASIN

The basin under discussion (Fig. 1) consists of a sedimentary area 400 miles in length from north to south and 175 miles in greatest breadth, bordering Indian Ocean between the Northampton mineral area on the south, and Northwest Cape and the mouth of Ashburton River on the north. This basin includes the greater part of Lyndon, Gascoyne, Murchison, and Edel districts of Northwest Division of the state, but overlaps into the north end of Southwest Division. The principal city is Carnarvon, besides which the only villages are those of Onslow and Gascoyne Junction. The area is largely covered by great sheep ranches, or "stations," which constitute the principal industry of the few hundred white inhabitants. One main "motor road" traverses the area from Onslow south to Gascoyne Junction and thence to Mullawa. Although no figures are at hand, it is estimated that Carnarvon may be a town of 1,000 persons, Onslow may have 200, Gascoyne Junction a score or less, and the average white population of a northwest sheep "station" is barely a dozen persons. The sparsely settled nature of the country will be understood when it is said that a motor trip from Broome (in northern Desert Basin) south to Mullawa (the rail head, south of Northwest Basin) over the main highway takes one past only about 35 houses outside the villages of Port Hedland, Roeburne, and Onslow. Since the only industry is sheep farming, a single "station" consists of hundreds of thousands of acres and frequently carries a hundred thousand head of sheep or more.

PERMO-CARBONIFEROUS ROCKS OF NORTHWEST BASIN

The stratigraphy may be likened in general to that of Desert Basin, with which it was doubtless once connected, either around

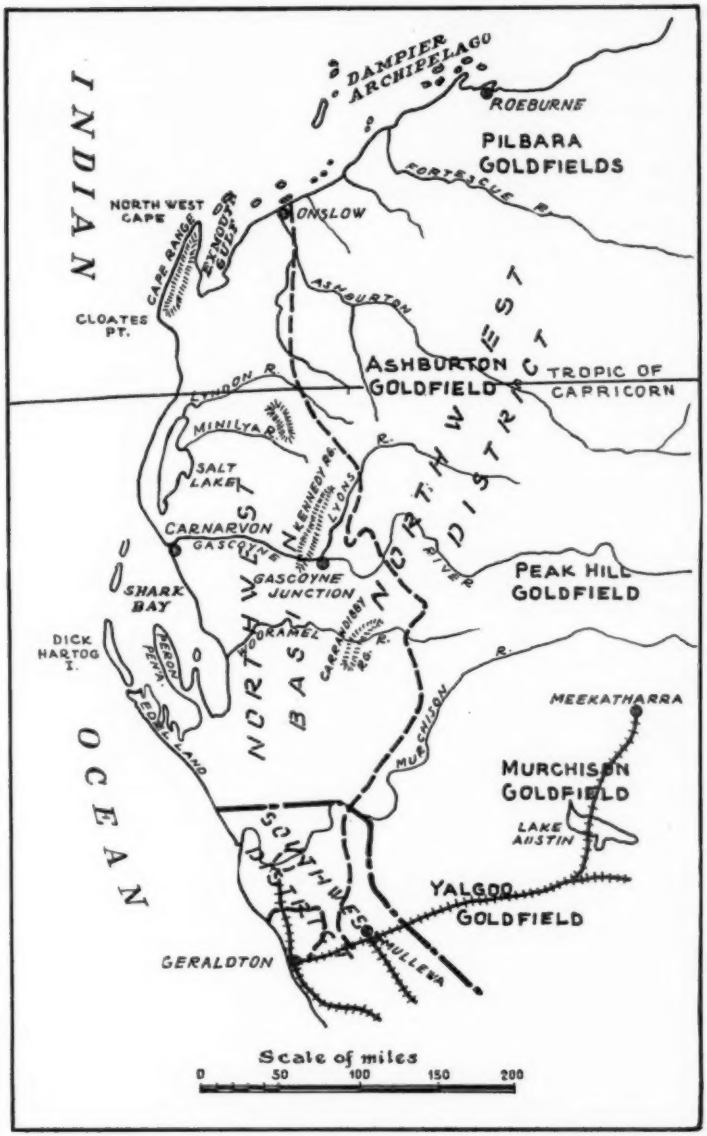

FIG. 1.—Map of a part of Western Australia, showing the Northwest Basin

the north end of the intervening crystalline and metamorphic plateau, or over its crest, a distance of 300 to 400 miles.

The most extensive strata in Northwest Basin are of Permo-Carboniferous age. They cover a large area of southeastern Lyndon District, the greater part of Gascoyne, the southwest corner of Lyons, about half of Murchison, and extend into the northeast corner of Victoria District. The eastern border of this Permo-Carboniferous area is intricate, with many projections into the principal valleys which drain the ancient rocks of the interior plateaus to the east. As in Desert Basin, there is a "Lower Series" and an "Upper Series" of Carboniferous and Permo-Carboniferous age, according to the nomenclature of earlier geologists. The "Lower Series" contains some limestones, calcareous sandstones, and perhaps thin shales, but no important shales were seen. The "Upper Series" is entirely sandstone. The combined beds are fully 2,000 feet thick and probably much thicker.

The approximate top of the "Lower Series" is marked by a great tillite bed or ancient glacial deposit, the Lyons conglomerate, which can be traced from north to south by a practically continuous outcrop more than 200 miles, constituting a prominent key bed. This tillite appears to be represented by a similar conglomerate in the Coastal Plain basin, by striated boulders found by Talbot and others at intervals throughout the northern part of Desert Basin, and possibly (though not probably) by a light-colored tillite containing rounded and striated pebbles found by the writer 400 miles east of Onslow on Oakover River in the vicinity of "Braeside Station"—an outstation of Warrawagine Station—apparently an outlier of the beds of Desert Basin.

Fossils of Permo-Carboniferous age have been obtained by the government geologists from the "Lower Series" at many places and from the "Upper Series," at one place at least, on the crest of Kennedy Range near Trig Station K-37, just north of Gascoyne River. Although the beds appear to be in perfect conformity, some inconsistency is suspected by the writer because of the fact that the beds on Kennedy Range lie almost flat or have a barely perceptible dip to the west, whereas anticlines, synclines, and domes of moderate size exist in the belt lying in the valleys directly east of Kennedy Range and several hundred feet lower. A mid-Permian unconform-

ity is claimed to be in total discordance with known conditions; yet it might not be surprising if one were found since one is already known in the state of Queensland. Other possible evidences of such an unconformity exist, but whether or not it can be proved will doubtless be elucidated by later government reports.

Boulders in the Lyons conglomerate are of all sizes, and contain practically all kinds of older rocks known in that part of Western Australia. A considerable proportion of them have smoothly polished and striated faces. In one place this tillite has been uplifted in the form of a perfect dome which exists as a Lyons inlier in the younger rocks. No glaciated surfaces have been observed, but the tillite in itself is the most perfect the writer has observed in a country where tillites are common.

Although not necessary for a consideration of any particular problem discussed herein, publication of the names of identified Permo-Carboniferous species collected on the recent expedition and determined by Dun may be of value. The determinations were made through the agency of Professor David and the courtesy of Mr. E. C. Andrews, the government geologist of New South Wales. All the species are from the so-called "Lower, or Limestone Series" of the Permo-Carboniferous and were collected on the east side of Kennedy Range southeastward to Dairy Creek Station.

LIST OF PERMO-CARBONIFEROUS SPECIES COLLECTED BY THE WRITER (DETERMINATIONS BY W. S. DUN)

Amplexus pustulosus, Hudl.
Crinoid stem ossicles
Phyllopora, sp. undescribed
Stenopora, 2 species
Spirifera marcoui, Waagen (sp. by Ethridge, son)
Spirifera umsakheylensis (? not Davidson)
Spirifera, cf. *lata* (Ethridge and Foord, not McCoy; will be renamed *maitlandi*)
Spiriferella australasica, Ethridge, son
Cleiothyris macleayana
Chonetes pratti, Davidson
Monilopora nicholsoni, Ethridge, son

Fenestella, 2 species
Aulosteges baracoodlensis
Productus Sp. nov. (named P. *clarkei*)
Productus pellus
Pleurophyllum australa, Hinde

A comparison between the strata in the east escarpment of Kennedy Range and those in the north escarpment of Desert Basin is interesting. In both places the rock is essentially fine-grained, white, or very light gray, frequently soft, porous sandstone, mainly siliceous to chalklike, with no determinable calcareous mixture. The rock is finely stratified and contains ferruginous and cherty concretions parallel to the bedding.

The Desert Basin formations and those of Northwest Basin are overlain in a seaward direction by strata of supposedly Jurassic age, which generally have characteristics similar to the Permo-Carboniferous rocks, and may not be susceptible of differentiation on lithologic evidence alone.

STRATA OF MESOZOIC AGE

Mesozoic rocks, which appear to be mainly of Jurassic age in this basin, extend in a belt of variable width from a point in Ashburton District, east of Onslow, south across Lyndon, Minilya, Gascoyne, Wooramel, and Murchison rivers. The belt is possibly 75 miles wide near its south end where these rocks appear to overlap the granites of the Northampton mineral area. Insufficient fieldwork has been done definitely to differentiate the Mesozoic beds everywhere.

The probable Jurassic rocks are in general fine-grained, white or very light gray sandstones, with a possible thickness of 1,000 feet. Some beds of Cretaceous age may be associated with them. Rocks of probable Jurassic age were encountered in the original artesian well at Pellican Hill near Carnarvon at the mouth of Gascoyne River, at depths between 1,200 and 1,360 feet. It is possible that some beds of Jurassic or Cretaceous age may occur on the western slope of Kennedy Range and fossils of these ages have been found by Gibb Maitland in the vicinity of Yannarie River in the northern part of the basin.

STRATA OF TERTIARY AGE

A continuous broad belt of probable Tertiary rocks extends from the mouth of Ashburton River near Onslow, south beyond Carnarvon and Hamelin Pool, across the full width of Edel District. These beds probably constitute the entire area of peninsulas and islands in Shark Bay. So far as superficial observations are concerned, the strata do not appear greatly different from those of Jurassic age, but are in many places recognizable in the field by topographic evidence, and recently they have been specifically referred to as of Oligocene age by Mr. Chapman, who identified *Foraminifera* collected by the writer on Cape Range west of Exmouth Gulf. Fossils from the deep artesian well at Pelican Hill, Carnarvon, are also reported to show Tertiary fossils at depths from 1,090 to 1,340 feet.

The Tertiary and Post-Tertiary strata of Desert Basin (exact ages often in doubt there) for convenience were classified as in the following table:

TERTIARY AND POST-TERTIARY STRATA IN DESERT BASIN

No.	Probable Age	Elevation (Feet)
1. "Pindan sands"	Jurassic to Recent	0–800
2. Red soil zone	Tertiary to Recent	0–10
3. Consolidated sand dunes	Early Recent	0–60
4. Raised sea-beaches of sandstone, limestone, comminuted shells	Early Recent	0–30
5. "Coquina" or shell rock	Early Recent	0–20
6. Sea-level "marshes" or plains	Late Recent	0–3½
7. Unconsolidated sand dunes and sand ridges	Present	0–500

All of these deposits except No. 2 exist in Northwest Basin. In this basin are also found at least 1,000 feet of soft chalky to hard, white to gray sandstones and limestones which attain their maximum development in Cape Range extending from Pt. Cloates to Northwest Cape, forming the backbone of the peninsula west of Exmouth Gulf and rising more than 1,000 feet above sea-level. These beds apparently cover a wide coastal area and are certainly in part Oligocene according to the determinations of Chapman and Dun.

GEOLOGIC STRUCTURE OF NORTHWEST BASIN

As in Desert Basin, prominent structures exist, both in strata of Carboniferous age, on the east side of Kennedy Range, and in the

Oligocene sediments of the northwest coast. In the last-mentioned belt a pronounced anticline forms the peninsula west of Exmouth Gulf, terminated by Northwest Cape and rendered almost inaccessible by recent dune areas and minor folds which may be repeated at intervals southeast to the vicinity of Winning Pool. East and north of Kennedy Range, in the eastern part of the basin, less prominent but none the less true anticlines were found—one noticeable dome involving a core of Lyons conglomerate. Any or all of these structures might be of interest if other conditions were even slightly favorable, but, as in Desert Basin, no other fundamental factor appears satisfactory.

SIMILARITIES BETWEEN NORTHWEST AND DESERT BASINS

One might suppose that Northwest and Desert basins have few characteristics in common. For instance, they are separated by a belt of pre-Cambrian rocks 350 miles wide where narrowest, and rising in places over 4,000 feet above sea-level. Desert Basin is roughly quadrilateral in shape, with its longer dimension approximately at right angles to the coast; whereas Northwest Basin, like Coastal Plain Basin farther south, constitutes a belt, nowhere over 175 miles wide, parallel to the coast from Onslow to Murchison River.

As the name implies, Desert Basin is composed largely of a desert. Enormous areas of it are barren and sandy, whereas the greater part of Northwest Basin is prosperous pastoral country in which two score artesian wells have been sunk, yielding some of the greatest flows of water in the Commonwealth and proving an area of perhaps 15,000 square miles to have artesian possibilities. Nevertheless, Northwest Basin is not devoid of uninhabitable areas. There is no highway south along the coast from Carnarvon to Geraldton, for impassable sand hills cover much of the country between Hamelin Pool Post Office (115 miles by air-line south of Carnarvon) and Geraldton in Coastal Plain Basin. Another extensive sandy area is that southwest of Exmouth Gulf, between it and Cape Range. The great dunes here were crossed with difficulty in a Dodge car.

Aside from their similar barren conditions, Northwest and Desert basins are similar in that each has a great escarpment, which, in the case of Northwest Basin, bounds Kennedy and Carrandibby ranges on the east. As in Kimberley District, so in Gascoyne Dis-

trict of Northwest Basin, the escarpment rises vertically 200 to 300 feet higher than the valley and is apparently inaccessible to vehicle or animal at any place from its south end near Gascoyne River to a point on Merlingleigh Station, a distance of about 50 miles. North and south from Kennedy Range its topographic features are repeated at intervals, represented by a smaller range of hills directly south of Gascoyne River, by Carrandibby Range 50 miles south, and probably also by Moogooloo Range north of Minilya River, so that, throughout a distance of 150 miles, the escarpment feature is prominent in some degree for intermittent but considerable distances.

As with the plateau escarpment in Desert Basin, so with that of Kennedy Range in Northwest Basin, the strata consist of fine-grained, white, non-calcareous sandstones, which dip west at angles of less than 5 degree with only slight reversals. No limestones or shales are known in either escarpment. Few fossil localities exist. No reverse dip of more than a fraction of a degree, and this for a short distance only, is visible in the face of Kennedy Range. As is the case with the southwest slope of the Desert Basin plateau, so with Kennedy Range, the land descends gradually, from an altitude of approximately 1,000 feet on the escarpment, westward to the Coastal Plain several hundred feet lower. Somewhere near the west base of Kenney Range the Permo-Carboniferous rocks pass beneath the Jurassics.

Thus the north escarpment of the Interior Plateaus of the Desert Basin of southern Kimberley Division appears similar topographically, lithologically, and stratigraphically to that forming the east face of Kennedy and Carrandibby ranges in Gascoyne and Lyndon districts of Northwest Division. It is evident that the strata of Northwest and Desert basins are contemporaneous and were once probably connected and that similar stratigraphic and structural conditions prevail in each.

THE "CAPE RANGE" FORMATION

An unexpected discovery was in the "Cape Range," where white limestones and interstratified chalky beds form a prominent anti-

cline rising from below sea-level on the west side of Exmouth Gulf to a height of more than 1,000 feet in the center of the range, intersected by deep gorges extending several miles into it. Some of the chalky beds are full of Oligocene types of *Lepidocyclina* and *Cycloclypeus*, identified by Mr. F. Chapman from the writer's foraminiferal collections. The beds lie flat on top of the range and dip 8° E. on the lower east flank.

East of the anticline of Cape Range other anticlines were found, one of which, on Giralia Station, 20 miles east of Cape Range, has a height of at least 300 feet and a breadth of 10 miles.

Large areas along the coast and for some miles back from it between Northwest Cape and Hamelin Pool may constitute part of the same formation.

SOME ADJACENT SEDIMENTARY AREAS

An interesting section 7 miles in breadth, consisting of apparently ancient rocks, lies 35 to 42 miles east from Onslow. More or less continuous outcrops were passed on a northeast-southwest traverse, all dipping at an average angle of 20° N. 60° E. These strata, if not duplicated by unseen faults, appear to be 13,000 feet in total thickness. They consist of rather uniformly hard, light gray, thick-bedded quartzites, with some medium-grained sandstone.

Although this belt of outcrops appears to lie on the strike of the Mosquito Creek beds (pre-Cambrian) mapped less than 100 miles to the south, the rocks are similar in character to many Permo-Carboniferous rocks where surface-hardened. The locality was not observed to be cut by quartz veins or by granite, as were the Mosquito Creek beds seen elsewhere; and the only intrusion noticed was a large dike of basalt apparently occupying the center of an anticlinal fold just west of Peedamullah Homestead.

Similar gray quartzites, also of great thickness, seen in the area between Nanutarra and Uaroo homesteads, south of Ashburton River, are underlain by at least 2,000 feet of schists. The formation south of Nanutarra is folded into several great anticlines in the center of which valleys have been eroded; but in that area the quartzites and schists are intruded by quartz veins, granites and gneisses.

RESERVOIR ROCKS, COVER, AND PETROLIFEROUS CONTENT

There is no question of porosity, for thousands of feet of white or gray sandstones exist, similar to those in Desert Basin, suitable for carrying oil under other circumstances. They are mainly siliceous and comprise nearly the entire Permo-Carboniferous portion of the stratigraphic section to the general exclusion of shales. Few, if any, cover rocks are known, and only a few feet of shale were actually seen or authentically reported in the basin. Thus it seems a physical impossibility for oil to have remained in these rocks even if it ever formed. The Oligocene limestones may have formed oil, which, however, is not supposed to have remained in quantity, for these limestones are everywhere open and porous and, so far as observed, are not overlain by shales or other impervious rocks.

Enquiries were made for reports of actual oil, and in one or two instances somewhat vague statements were received of oil showings on the outlets of artesian wells, but in every observed case the substance was found to be merely a trace of iron oxide or vegetable scum.

WELLS DRILLED TO DATE

No wells have ever been drilled in search of oil. Nowhere among the two score, more or less, artesian wells was any trace of oil or natural gas found.[1] These wells range from a few hundred to more than 3,000 feet deep and one yielded as much as 2,000,000 gallons of water a day.[2] In addition, a few of them furnish definite information relative to stratigraphic conditions and serve to confirm conclusions arrived at from surficial studies. It is true that in some cases shaly beds were reported; but in that region any fine-grained material is generally termed "shale," hence such reports were not considered important from the standpoint of oil occurrence. Moreover, if oil existed in commercial quantity anywhere in Northwest Basin, it would seem that some trace of oil or gas should have been found in one or more of the numerous wells.

[1] The nearest to actual gas occurrences were several reported "flashings" of gas in water emerging from flowing wells; but several of these were tested with a match and not found to flash noticeably at the time.

[2] Reports of A. Gibb Maitland in publication of the First, Second and Third Interstate Conferences on Artesian Water, with accompanying maps, sections, and other illustrations.

The following list gives a fair idea of the nature of the wells:

PARTIAL LIST OF ARTESIAN WELLS OF NORTHWEST BASIN[1]

No.	Name	Locality	Date Completed	Depth in Feet	Amount of Flow*
1.	Onslow bore	Onslow	1899	1,729	120
2.	Pelican Hill	Carnarvon	1903	3,011	5?5,000
3.	Butcher's, No. 1	Near Carnarvon	1904	1,650	1,000,000
4.	Grierson's Tank	Carnarvon	1905	1,510	93,000
5.	Burt's, No. 1	Brickhouse Sta.	1905	2,632	630,000
6.	Burt's No. 2	Brickhouse Sta.	1906	1,546	1,096,000
7.	Butcher's No. 2	Near Carnarvon	1906	1,391	400,000
8.	Butcher's No. 3	Near Carnarvon	1906	1,461	470,000
9.	Burt's, No. 3	Brickhouse Sta.	1907	1,813	494,000
10.	Burt's, No. 4	Brickhouse Sta.	.....	1,460	500,000
11.	Snook & Waldeck	Carnarvon	1907	1,281	1,100,000
12.	Minilya Sta. No. 1	Yankee Tank	1907	1,000	750,000
13.	Minilya Sta. No. 2	Gnabarnarra	1908	1,408	600,000
14.	Morell & Hearman	Carnarvon	1908	1,404	1,000,000
15.	Maud's Landing	Near Point Cloates	1909	2,359	654,000
16.	Gladstone	Hamelin Pool	1909	523	2,000,000
17.	Davis and Hankinson No. 1	Warroonga Sta.	.....	1:280	?
18.	Davis and Hankinson No. 2	Warroonga Sta.	.....	1,180	500,000
19.	R. F. Sholl No. 1	Marrow Sta.	.....	1,500	?
20.	Minilya Sta. No. 3	Combabado	1910	1,659	1,000,000
21.	Matheson's No. 1	Cardabia Ck.	.....	2,161	?
22.	Bunbury's	Winning Pool	.....	2,650	?
23.	Bunbury's	Mia Mia Sta.	.....	2,700?	1,000,000?

* In gallons of water a day when allowed to flow uncontrolled.

SUMMARY AND CONCLUSIONS

Not a trace of oil is known ever to have been found in any of the two-score artesian wells drilled between one and three thousand feet deep. Only traces of natural gas have been reported in any of them and these could not be substantiated at the time of the writer's inspection. So far as observed, the shales in Northwest Basin are entirely inadequate to act as a suitable cover to hold oil in the thousands of feet of sandstones that exist there, even if oil ever existed in these rocks. Sources of origin may have existed but are of theoretical interest only. Structures exist, but these are inconsequential, since other fundamental conditions are unfavorable.

[1] Mainly abstracted from A. Gibb Maitland, *Report of Second Interstate Conference on Artesian Water*, Brisbane, 1914, pp. 252–53 (later issues not available for study).

PRELIMINARY REPORT ON THE GEOLOGY OF THE OIL FIELDS IN NORTH (RUSSIAN) SAKHALIN[1]

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ABSTRACT

The area described is the eastern coast of the northern, or Russian, part of Sakhalin Island. The surface features are grouped in lagoon, terrace, hill, and mountain zones. Lagoon formation is particularly discussed as being caused in part by coastal upheaval, formation of sand bars, and lines of faulting. The formations exposed in the oil districts are shales, sandstones, and conglomerates of Tertiary age, grouped in lower, middle, and upper divisions, partly on a physical and partly on a fossil basis. The general strike of the region is north-south, parallel to the coast. Seven main anticlines are marked by pronounced dips and by oil seepages and asphalt beds. Considerable drilling has been done, both by primitive methods and by diamond-drilling, cable tools, and rotary rigs. In the first half of 1925, three or four wells in the Oha field produced 41,741 barrels of oil. An analysis of oil from a depth of 180 meters shows no gasoline. One test well reached a depth of 1,504 meters; at 879 meters 20 barrels of oil were found, and at 1,227 meters 200,000 cubic feet of gas blew out.

INTRODUCTION

The existence of petroleum in North Sakhalin has been known about forty years, but because of climatic conditions and general inaccessibility all attempts to exploit the possibilities of the district have been checked. Even the Russian government did not pay much attention to the development of this natural resource. Since 1890, the Russian Geographical Society and Russian Geological Survey have sent many geologists to make preliminary investigations of the oil-producing districts; on the whole, however, the geological features did not come into light clearly through the geological surveys.

Several test wells were drilled in different oil fields on the eastern coast of North Sakhalin, namely, at Nutovo, Boatasin, Oha, and Niuvo, but they were all shallow in depth and did not strike any rich oil deposits.

Since the great European war, many Japanese geologists have visited the fields, particularly those on the eastern coast, for scientific

[1] Prepared for presentation before the Association at the New York Meeting, November, 1926.

[2] Government geologist of the Imperial Geological Survey of Japan.

as well as economic reasons, and they have obtained a thorough knowledge of the oil fields. The present report is intended to present a study of rock formations and geological structure of the oil fields, but it is beyond the scope of this paper to make specific predictions as to location or possible production of the wells.

TOPOGRAPHY

The eastern coast of North Sakhalin, between Lat. 51° and 54° N., has peculiar topographical features. It can be divided into four zones as follows: (1) lagoon, (2) terrace, (3) hill, and (4) mountain.

1. *Lagoon zone.*—The most characteristic feature on the coast is the arrangement of many lagoons in a row along the coastal line. Though differing in shape, they generally extend north and south. Kiacle, the largest of the lagoons, has an area of more than 90 square miles. Napirisky, Nuisky, and Chaisky have areas of 30, 20, and 18 square miles, respectively.

The lagoons are usually separated from the Pacific Ocean by long, narrow, straight bars made up of sand dunes. These bars are less than 20 meters high and generally less than a mile wide. The dunes have steeper slopes toward the ocean and more gentle slopes toward the lagoons. The western parts of the lagoons are shallow in waters but the eastern parts near the sand bars are deeper. The lagoons have one opening to the ocean; rarely two.

2. *Terrace zone.*—On the western side of the lagoon zone are broad, flat-topped terraces, less than 50 meters above sea-level. These terraces are a plain on the top but end at the edges of the lagoons in steep cliffs. The terrace zone extends south from the neck of Shumit Peninsula to Lunsky lagoon, a distance of 150 miles parallel to the shore. The zone differs in width from 4 to 2 miles, and along its edges are found one or two other low terraces facing the lagoons. The cliffs at the edge of the terraces are believed to have been formed partly by erosion by the sea and partly by the denudation by ice and snow.

3. *Hill zone.*—The terrace zone increases in height westward, finally losing its terrace character in the hill zone which rises from 50 to 150 meters in elevation and continues from north to south,

GEOLOGICAL MAP
OF THE
OIL FIELDS
IN
NORTH (RUSSIAN) SAKHALIN
Chaisky
Nutovo
Nutovo Oilfields
Nutovo Oilfield
Nutovo Oilfield
Nutovo Oilfield

although crossed by many river valleys. On the northern part of the coast, it forms the neck of Shumit peninsula. Many oil fields lie in this zone. The zone is characterized by hard or calcareous sandstones. The terraces are composed of loose sand and gravel. The hardness of the strata has a close relation to the topographical features of the coast.

4. *Mountain zone.*—A mountain range, 200 meters or more in height, extends from Pilitoon southward, on the western side of the hill zone. The highest peak reaches a height of more than 600 meters. The range becomes lower along the course of Tuimi River but rises again farther south near Lunsky. At Delir de la Croail, the range is near the shore and makes great cliffs against the ocean.

The southern part of the mountain range is composed of Paleozoic formations and has steeper and higher peaks than the northern part, which is composed of Tertiary formations.

COASTAL UPHEAVAL AND FORMATION OF LAGOONS

From the topographical features it is clearly shown that in the eastern coast of North Sakhalin two or more upheavals of land have occurred since the deposition of Tertiary formations. The upheaval of the coast has a very close relation to the formation of lagoons, and may be counted as the most important factor. About the origin of lagoons, three factors may be pointed out: (1) coastal upheaval, (2) formation of sand bars, and (3) tectonic lines.

1. *Coastal upheaval.*—By coastal upheaval, the littoral terraces under sea water were raised to the surface and some of the lower places or basins in the terraces became bays or lakes. These bays, by the formation of sand bars, became lagoons of today.

2. *Formation of sand bars.*—Sand bars dividing lagoons from the ocean extend north and south, making straight lines. The longest bar has a length of about 20 miles. The strata which constitute the eastern coast are mostly loose, soft quartz sand or argillaceous sandstones. This loose sand or sandstone could easily be eroded by streams flowing into the bays, and the eroded material could be deposited in a zone where stream current and sea waves could keep an equilibrium of force.

There must at one time have been less agitation of the water, and in the long run of time the deposited sands may have accumulated and formed the sand bars in that zone, as now seen, and the bays may have been changed into lagoons.

3. *Tectonic lines.*—A few lagoons like Urkt, or Torkuit, are believed to have close relation to tectonic lines in their origin. Fault lines pass through the lagoons, and along these lines some depression probably took place and helped in their formation.

WATER SYSTEM

There are several rivers on the eastern coast of North Sakhalin. Tuimi River is the longest one and makes a main line of communication between the eastern and western coasts of North Sakhalin. From its mouth, where it empties into Nuisky lagoon, up to Adatuimi village, a distance of about 100 miles, it is navigable. Besides this river, Waar River, Gigian River, and Pilitoone River are fairly long but do not exceed 30 miles and are scarcely navigable at all. In general, the valleys of these rivers are broad and both sides are bounded by hills or terraces which have steep slopes, especially on the south side. The valleys are usually occupied with so-called "tundra"—marshy moss-ground peculiar to Siberia and Sakhalin. Most of the rivers flow east into lagoons or the Pacific Ocean.

GEOLOGY

The rock formations which comprise the oil fields of the eastern coast are all of the Tertiary period. The exposures of rocks are very bad, being covered with a thick surface soil, or "tundra," which is very difficult to clear away.

Geological examination can be made in most places by digging deep holes or channels. The plains, or some parts of the terraces, consist of Quaternary formations, but these are not important.

TERTIARY FORMATION

The Tertiary formation is divided into five series, based on lithology, from lower to higher as follows:

A. Lower division
   1. Basal conglomerate and sandstone series

B. Middle division
   2. Hard- and soft-shale series
   3. Sandstone series
   4. Dark-gray shale series
   5. Sandy shale series
C. Upper division
   6. Upper sandstone and conglomerate series

1. *Basal conglomerate and sandstone series.*—This series forms the base of the Tertiary formations in the oil fields and overlies unconformably the Paleozoic formations. The lower part of the series is conglomerate, the pebbles of which are Paleozoic and igneous rocks like granite, or quartz porphyry. The upper part of the series becomes quartz sandstone, with a light-brown or bluish color on the fresh faces. In this sandstone, a few thin coal seams are intercalated. The total thickness of the series is less than 150 meters.

2. *Hard- and soft-shale series.*—This series occupies a broad area and attains a great thickness in the southern parts of the oil fields. It overlies the basal conglomerate and sandstone series conformably. The lower part is rather hard but has a tendency to break off in thin plates; it is brownish gray, or dark gray, in color. The characteristic of the lower part is the presence of calcareous bowlders in which some shell or plant fossils are found. The upper part of the series is massive and soft; its stratification is not distinct. Some layers of thin sandstone and pumiceous sandstone are intercalated in the series. Oil seepages occur in them.

3. *Sandstone series.*—The hard- and soft-shale series is conformably overlaid by an upper sandstone series. The sandstone is fine grained and bluish gray, and in many places it is argillaceous. Conglomerates, sandstones, and shales of less than 2 feet in thickness are intercalated in this series. The whole thickness is estimated to be about 1,700 meters. In the upper part of the series, the number of intercalated shales increases greatly and the series changes into an alternation of sandstone and shale. The alternation is remarkable because it contains many coal seams. *Tellina* sp., *Nassa* sp., *Mactra* sp., and *Natica* sp. are found in argillaceous sandstones.

In the alternation of sandstone and shale, the following fossils are found:

Natica helicoides Jonstr.
Natica clausa Desh.
Cardium californiense Desh.
Thyasira bisecta Conr.
Yoldia sp.
Lucina sp.
Nucula sp.

These plant remains are found: *Viburnum*, *Almis*, and *Salix*.

4, 5. *Dark-gray shale series and sandy shale series.*—These two series are the most important of all the Tertiary formations from an economic point of view. The dark-gray shale series lies at the lower part and the sandy shale series at the upper part. The former is dark gray or bluish gray and ordinarily hard, but in some places it becomes siliceous and very hard. The shales are intercalated with many conglomerates and sandstones which have different thicknesses. The sandstones are quartzose but there are also a few calcareous and pumiceous sandstones.

In the calcareous sandstones, many shell fossils are contained. The dark shale series gradually changes into the sandy shale series by increasing its sandy character in the upper part. The sandy shale is soft in most places. These two series cannot be distinctly separated. They occupy broad areas at Oha, Ehabi, Nutovo, and Katanguri oil fields. The dark shale from the Oha oil field contains 0.60 per cent of hydrogen and 0.66 per cent of carbon.

The fossils found in the dark-gray shale series are as follows:

Natica clausa Var. *ganthostom* Soworby
Nucula sp.
Thyasira bisecta Conr.
Mya Crassa
Mactra sp.
Tapes sp.
Venus sp.
Fusus sp.
Nassa sp.
Tellina sp.
Cardium sp.

The whole thickness of these two series is believed to be about 3,500 meters.

6. *Upper sandstone and conglomerate series.*—This series occupies the uppermost part of the Tertiary formations in the oil fields and has the broadest area of distribution. It includes white-gray sandstones, fine-grained conglomerates, and calcareous sandstones. It is divided into the upper and the lower parts. The lower part is an alternation of sandstone and conglomerate. Thin shales and calcareous lenticular sandstones are intercalated in the sandstones.

Conglomerates are usually thin and loose, and their pebbles are mostly Paleozoic rocks mixed with some granite and diorite.

The upper part of the series is separated from the lower by thick calcareous sandstone, and the general character of the two parts is similar. In calcareous sandstones there are found many shell fossils as follows:

Tellina venulosa Schrenck
Macoma dissimilis Martens
Siliqua sp.
Yoldia aff. *notabilis* Yokoyama
Echinarachnius aff. *Parma* Lam.
Buccium sp.
Tellina nasuta Conrad
Mactra sulcataria Desh.
Mactra aff. M. *veneriformis* Desh.
Spisula sp. (S. cf. *lemiphilli* Dall)
Tellina dissimilis Martens
Mactra sakhalinensis Schrenck
Pecten cf. *cooperi*
Aulus costatus
Venus sp.

The thickness of the series is less than 2,600 meters.

GEOLOGICAL AGE AND POST-TERTIARY UPHEAVAL

From the fauna obtained from the Tertiary formations in the eastern coast of North Sakhalin, it is known that they are of Miocene and Pliocene time. They are in successive layers and of marine origin. The general strike of the strata is north and south, forming many anticlinal and synclinal structures. After the deposition of these beds upheavals of the shore took place at least more than twice. Mountain-making forces were working constantly during the period and resulted in the folding now seen. Littoral terraces came out of the sea, and the lagoons have been formed in the present condition as previously stated.

QUATERNARY FORMATIONS

Quaternary deposits in the oil fields can be divided into (1) diluvial deposit (or Post-Pliocene) and (2) alluvial deposit.

1. *Diluvial deposit.*—This deposit is composed of sand and gravel layers with thin layers of clays. A part of the terrace zone and river terraces are believed to be of this deposit. It is a remarkable fact that in the diluvial terrace near lagoons, large boulders of granite or diorite are found, especially in the northern part of the oil fields. The boulders are commonly angular and large, some of them measuring 13 feet in length. Their angular forms and the freshness of surfaces

leads to the conclusion that they were not carried far and were not exposed to long weathering action. Close observation in the oil fields and nearby shows that there is no exposure of such rocks which might be taken as the origin of the boulders, and I am inclined to believe that these big boulders were carried by floating icebergs, or snow, from a place not far from Sakhalin Island—probably from Kamchatka or Siberia. The deposit cannot be easily distinguished from the uppermost Tertiary formations, and some geologists believe it to be a post-Pliocene deposit.

2. *Alluvial deposit.*—The alluvial deposit consists of sand and gravel layers as in the diluvial deposit. It is very loose quartz sand intercalated with thin layers of clays. In the bottom of the "tundra," thin layers of peat are found.

THE PRESENT CONDITION OF THE OIL FIELDS AND THEIR GEOLOGICAL STRUCTURES

There are many anticlinal structures in the oil fields. Between the rivers of Nampie and Oha are seven main anticlinal structures as follows: (1) Oha, (2) Ehabi, (3) Paromai-Quidrany, (4) Nutovo, (5) Wenie, (6) Katanguri, and (7) Congie. Along these anticlinal structures there are many oil districts.

1. *Oha oil fields.*—The Oha oil field is situated on the northwestern side of the Urkt lagoon at a distance of 3 miles. The strata which occupy the anticlinal folding are the dark shale series, and in part the sandy shale series, which contain many sandstones and conglomerates. The anticlinal axis has a length of about 3 miles; on both flanks of the axis, the strata dip less than 25°, and in most places about 15°. The eastern flank has steeper dips than the western flank. The oil field was bored by Zotof in 1889 for the first time, but the well did not strike rich oil. In 1921, Hokushin-Kai, a Japanese Oil Company, bored three test wells on the west side of the axis and found fairly rich oil seams at shallow depths. Being encouraged by this result, the company began to explore the field with wells of the rotary and cable system. Fourteen wells of different drilling systems were sunk and many oil-containing strata within the depth of 1,000 meters were discovered. Some wells have erupted three hundred barrels a day. The oil-containing strata are all quartz sand-

stones or argillaceous sandstones. About 41,741 barrels of oil were produced from three or four wells during the first half of 1925. Chemical analysis[1] of the oil which came from a depth of 180 meters is as follows:

ANALYSIS OF OIL FROM DEPTH OF 180 METERS, OHA OIL FIELD

Specific gravity	0.934
Water	Trace
Flushing-point	60° C.
Viscosity	16.25 at 15.5 C. 50.20 at 5.0 C.
Calorific heat	11,498
Impurities	0.02
Sulphur	.26
Ash	0.02
Paraffin	None
Freezing-point	Below −17° C.
Gasoline	0
Lamp oil	36.70 (150°–300°)
Machine oil	35.00 (300°–360°)
Residue	28.30 (above 360°)

There are many oil seepages in the field and most of them make asphalt lakes, so-called "kir[2] lakes." The largest asphalt lake has an area of 26,000 square meters. The thickness of the asphalt ranges from a few inches to several feet.

2. *Ehabi oil district.*—This oil district is situated on the west side of Ehabi and Azap lagoons. The strata which form the anticline are the dark-gray shale series and the upper conglomerate and sandstone series. The dark shales are hard and in places siliceous. The length of the anticlinal axis is more than 4 miles. On the west flank beds dip from 50° to 20° and on the east they dip between 15° and 40°. Two large faults parallel the anticlinal axis. The Hokushinkai Oil Company drilled three wells of the Kazusa system and reached a depth of 226 meters, but no rich oil seam was found. Many oil seepages occur along the axis. The largest one has an area of 400 square meters.

[1] Chemical Laboratory of Imperial Geological Survey of Japan.

[2] "Kir" means oxidized crude oil.

3. *Paromai-Quidrany oil district.*—The Paromai-Quidrany oil district is the area along the anticlinal axis between Paromai and Quidrany rivers. It is about 10 miles long. The strata are the upper sandstone and conglomerate series and the sandy shale series. The inclination of strata on both flanks of the axis is generally less than 40° but on the southern part in places more than 70°. A fault extends north and south on the west side of the axis. A few small oil seepages are found on the upper course of Paromai River.

4. *Nutovo oil district.*—Crossing the rivers of Kioniga, Pilitoon, Nutovo, Paromai, and Handooza, a long anticline extends north and south more than 20 miles. This is the longest anticline in the eastern coast of North Sakhalin. The strata are mostly the upper sandstone and conglomerate series and the sandy shale series, but in places the dark-gray shale series can be seen in the center. The eastern flank of the anticlinal fold is generally steeper than the western flank. In the lower course of Nutovo River, another small anticlinal structure can be seen. It is an overturned fold with the strata on both sides dipping more than 60° in the same direction. Extending north and south close to the fold is a fault along which are many large oil seepages—kir lakes—and gas eruptions. Two test wells, located on the eastern flank of the anticline, were drilled with the cable system by the Chinese Oil Company. One was drilled to a depth of 70 meters, although at 30 meters a little oil deposit was encountered. The other well was drilled 80 meters and much oil was reported. In 1920, the Hokushinkai Oil Company drilled two Kazusa wells in a kir lake to depths of 64 meters and 110 meters, respectively, but no rich oil deposit was found.

In the upper course of Nutovo River, along the main long anticline, the Hokushinkai Oil Company drilled a rotary well in 1921 to a depth of 1,504 meters. At 879 meters some twenty barrels of oil were found, and at 1,227 meters, 200,000 cubic feet of gas blew out. The character of the oils produced in these two districts is different.

From Nutovo northward, at Pilitoon, there is another oil district along Pilitoon River. The strata belong to the sandy shale series and the dark-gray shale series. On both sides of the fold the beds dip more than 30°. The Hokushinkai Oil Company drilled two wells in this district, one a diamond-drilled well and the other a Kazusa

well. They were drilled to 146 meters and 102 meters but no rich oil deposit was found. From Nutovo oil district southward, at Batasin, there is another oil district on the southern part of the same anticline. The formations belong to the upper sandstone and conglomerate series. The China Oil Company drilled three wells here in 1910. The deepest well reached a depth of 310 meters but none of them found much oil. The Hokushinkai Oil Company drilled a cable-system well 246 meters deep on the eastern flank of the fold. Because of difficulties in drilling, it took a long time to reach this depth. No rich oil deposit was found.

5. *Wenie oil district.*—Half a mile up from the mouth of Wenie River, which flows in Nuisky lagoon, there is one small anticlinal structure. The strata of the district are the upper sandstone and conglomerate series and the sandy shale series. The inclination of strata on both sides of the fold ranges from 20° to 40°. Many small oil seepages are found in the tundra along the stream. No drilling has been done here.

6. *Nutovo and Katanguri oil districts.*—A large anticlinal structure is found on the western side of Katanguri Lake, extending north and south with a total length of 6 miles. It reaches north to the mouth of Nogrik River. The strata belong to the upper sandstone and conglomerate series and the sandy shale series. On the south part of the structure the beds on both sides of the fold dip less than 20°, and on the north part they dip 15° more or less. There are many large asphalt lakes in the Katanguri district along the anticlinal fold. Nutovo oil district is situated on the northern part of the Kantanguri anticline. In 1901 Zotof bored two wells near the oil seepages along Nogrik River, on the western flank of the anticline. One well reached a depth of 317 meters and the other 450 meters, but both found only a little oil with gas and salt water. The Hokushinkai Oil Company drilled a well with the cable system on the eastern flank in 1920 and reach a depth of about 340 meters. Between 68 and 84 meters, ten barrels of oil were produced daily for a time. Besides this well, one Kazusa well was drilled to a depth of 46 meters, but no oil was struck.

About 2 miles south along the axis is the Wegrek oil district near Wegrek River. The Hokushinkai Oil Company drilled two wells

along the axis, one a diamond-drilled well which reached a depth of 198 meters and the other a Kazusa well which reached 80 meters. Both wells discovered a little oil between 40 and 60 meters.

South of the Wegrek district is the Katanguri oil district, on the west side of Katanguri Lake. Along the anticline there are many large asphalt lakes. The total area of these is larger than all the other oil seepages on the eastern coast of North Sakhalin. In 1921, the Hokushinkai Oil Company drilled two Kazusa wells, one diamond-drilled well, and two rotary wells. The first three wells were all shallow, the deepest one hardly reaching 70 meters. They secured several barrels of oil at a depth of less than 30 meters. One rotary well reached 764 meters and the other 720 meters. The former, situated near the top of the anticline on the east side, encountered many oil seams, among which the richest, it is said, produced twenty barrels a day.

Besides the previously mentioned oil districts, there are other oil districts at Congie and Chakkalesky; also, other anticlinal structures exist. Along these structures occur many asphalt lakes. These districts, however, are not yet well investigated.

THE RELATION BETWEEN ACCUMULATION OF OIL AND GEOLOGICAL STRUCTURE

As previously stated, the oil fields occur in Tertiary formations, and the districts of Oha, Ehabi, Nutovo, Nuivo, and Katanguri are all of the middle division. The fields are arranged parallel to the coast line, extending north and south. On the many anticlines there are large asphalt lakes—so-called "kir lakes"—and these lakes generally lie in the areas composed of sandstone or sandy shale. With all these facts and the result of many borings, it can be said that the most important factor for the accumulation of oil in the oil fields is the geological structure. The black-colored shales, or dark-gray shales, of the middle division seem to have a close relation to the origin of oil.

THE RESULTS OF OIL PROSPECTING ON SAKHALIN ISLAND BY JAPAN IN 1919–25

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ABSTRACT

Japan commenced drilling on Sakhalin in 1919, by means of rather primitive methods. In 1921 diamond drills and rotary rigs were added, and in 1923 cable tools were used. In 1925 work was almost suspended, pending treaty negotiations with Russia. Japan has prospected 13,000 acres of oil-bearing land on the eastern shore, a very small part of the oil belt which extends 250 miles along the coast. By terms of the concession from Russia in 1925, Japan is to prospect 300,000 acres which are to be divided into claims ranging from 40 to 100 acres, and arranged checkerboard-fashion, the alternating claims being retained by the Soviet Government, which may lease to a new applicant of any nationality. Results accomplished by Japan are encouraging for further exploratory work. Thirty-one holes have been drilled; 5 were dry; 17 showed oil; and 9 were producers, ranging from 9½ to 189 barrels a day. In the 8 oil fields of Sakhalin, oil has been found at depths ranging from 100 to 2,984 feet. Japanese geologists have proved the presence of anticlines postulated by Russian geologists. The oil is used as fuel for Japanese destroyers.

Since the occupation of Sakhalin Island by the Japanese in 1920 very little has been known outside of Japan about the oil prospecting carried on by them in that island. How eager they were not to let anybody get any information of their work was shown by the widely known incident when geologists of the Sinclair Oil Company were not allowed by Japanese authorities to stay on the Sakhalin and were sent back to Vladivostock, as quasi-prisoners, although an oil concession had been granted to Sinclair by the Moscow government. To be sure during the prospecting, Russian inhabitants of Sakhalin Island were employed by Japanese, but they were mostly ignorant people used only as unskilled workmen; moreover, staying permanently in Sakhalin Island, they could not bring out any news of the work carried on by the Japanese.

In the fall of 1925 Japan obtained from the Moscow Government an oil concession in Sakhalin Island. But before granting this concession, or even considering its conditions, the Soviet Government

[1] Introduced by R. E. Somers.

requested Japan to end at once the military occupation of Sakhalin Island and to return it officially to Russia. Both conditions referred to were fulfilled by Japan during the early spring of 1925. In March, 1925, the Sakhalin oil fields were already under protection of Russian militia, the first detachment of which arrived at the Okha oil field on March 9. About the same time an official Russian commission appointed by the Soviet Government to receive the island from the Japanese authorities arrived at Sakhalin Island. Among the Russian officials was a mining engineer, P. I. Polevoy, Director of Russian Far Eastern Geological Committee, who had previously worked many years on Sakhalin Island and is undoubtedly the best student of the geology of that island as well as of its oil and coal localities. In 1925 he stayed on Sakhalin about six months, visited all oil fields, examined the work accomplished by the Japanese, and got from them many geological and technical data, usually inaccessible to anybody outside of Japanese companies connected with the Sakhalin oil business. In a paper published in No. 8 of the Russian magazine "Nephtyanoye Khozyaystvo" (Oil Business), in 1925, Polevoy gives a detailed account of the results of the work secretly accomplished by Japan on Sakhalin during the five years of the occupation of the island by Japanese troops. Data published by him in the paper referred to have furnished material for the present article.

Japan displayed an interest in the Sakhalin oil business for the first time in 1916. Since that time Japanese industrial firms connected with mining, chiefly the Kukhara Company, tried to establish some connection with Russian mining enterprises operating on the island. Geological investigations were started by Japanese in 1918. In 1919 the Vice-Director of the Geological Survey of Japan, Mr. Kobayashy, was appointed the head of these investigations. Even at that time it was clear that, although the whole business was carried on as a private enterprise, the Kukhara Company was backed by official Japan. It was also no secret that the occupation of the island in 1920 by the military forces of Japan was undertaken chiefly in the interests of the Sakhalin oil business, although official declarations by Japan were different. From the moment of the occupation, the mining work of a private firm was carried on under protection

of expeditionary corps. It was also well known that since the very beginning the private company had been supported financially by the Navy Department of Japan. The contract between Soviets and Japan, concerning the Sakhalin oil concession, is signed on the Japanese side by the Khokusinkay Company which, during the last years, had carried on the whole prospecting in the Sakhalin. Into this big concern have been incorporated many of the most important Japanese firms, plus the Navy and Army Departments of Japan.

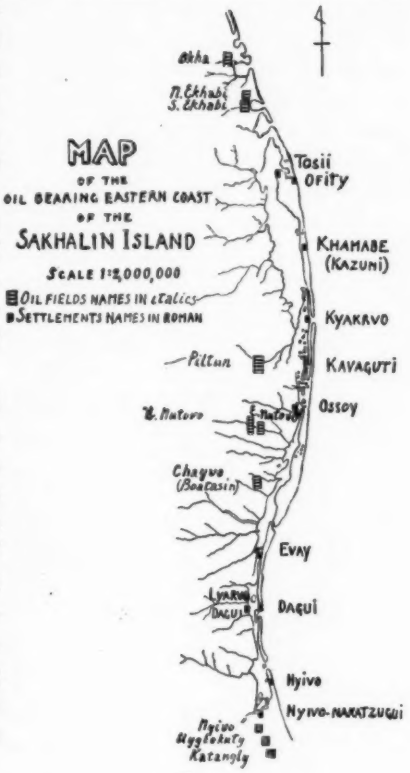

FIG. 1

The Japanese started drilling in 1919, at first in a rather primitive way, using a Japanese modification of the cable system in which the cable is replaced by strips of bamboo wound on a wheel more than 17 feet in diameter. Motive power is supplied by a man running within the wheel, thus turning it over and raising the bit or bailer.

In the same primitive way work was carried on in 1920. In 1921 and 1922, besides the earlier method, diamond-drill and rotary systems were used in different wells. In 1923 and 1924 the cable system was also added. In 1925 the work was suspended almost completely owing to the fact that negotiations for a treaty between Soviet Russia and Japan, relating to the oil concession in Sakhalin, were approaching such an end that business in Sakhalin was expected to start on a new basis.

Oil fields prospected by the Japanese company are located in three different regions along the eastern shore of the island and cover altogether 13,000 acres of oil-bearing land. This area is only a small part of the oil-bearing belt of the eastern coast of Sakhalin, which has been traced about 250 miles along the coast, covering many hundred thousand acres (Fig. 1). Among the other conditions of the contract referred to, the Japanese are obliged during the next year to choose about 300,000 acres of the oil land for the purpose of further prospecting. The lease so far granted to Japan contains 50 per cent of the whole acreage examined by the Khokusinkay Company. It must be subdivided into claims, each containing 40 to 100 acres, distributed in checkerboard order, the alternating claims remaining in the possession of the Soviet Government. These claims will be exploited by the Soviet Government or may be leased to a new applicant of any nationality. In an indirect way Japan has thus opened oil fields on Sakhalin Island to international competition after five years of a military occupation, during which time even the legitimate possessors of the island had not been permitted in the oil localities.

All the details concerning the wells are given in the following tables compiled by Polevoy from Japanese sources. Japanese meas-

TABLE I

SYSTEMS OF DRILLING AND NUMBER OF WELLS

Regions	Rotary	Hand	Cable	Diamond	Total
Okha	2	4	5	.....	11
Ekhabi	.....	3	.....	.....	3
Piltun	.....	2	.....	1	3
Nutovo	1	2	.....	.....	3
Boatasin	1	.....	1	.....	2
Nyivo	.....	1	1	.....	2
Uyglekuty	.....	1	.....	1	2
Katangly	2	3	.....	.....	5
Total	6	16	7	2	31

ures are expressed in the corresponding equivalents used in this country.

Results of the work accomplished by Japan are thus seen to be encouraging for further exploratory work. The per cent of completely dry holes is only 16.1 Nine of the wells would pay, and the output

of three of them is considered in Japan as a very high production. Among the Russian population of Sakhalin there is a rumor that one well at Okha was a gusher. The Japanese administration, however, positively denied this. Possibly the fact that the taxation of oil

TABLE II

DEPTHS OF THE WELLS AND THE RESULTS OF DRILLING

Districts	System of Drilling	Depths in Feet	Daily Output of Oil in Barrels
Okha	Rotary	2,207	4.7
Okha	Rotary	2,983	189.0
Okha	Cable	996	113.4
Okha	Cable	614	141.8
Okha	Cable	728	Dry
Okha	Cable	761	Dry
Okha	Cable	904	18.9
Okha	Hand	134	a little
Okha	Hand	305	9.4
Okha	Hand	448	9.4
Okha	Hand	173	Dry
Ekhabi	Hand	676	Traces
Ekhabi	Hand	360	Traces
Ekhabi	Hand	225	Traces
Piltun	Hand	304	Traces
Piltun	Hand	203	Dry
Piltun	Diamond	677	Traces
Nutovo	Rotary	2,984	18.9
Nutovo	Hand	193	Traces
Nutovo	Hand	330	Traces
Boatasin	Cable	734	a little
Boatasin	Rotary	12	Dry
Nyivo	Cable	1,011	a little
Nyivo	Hand	240	Traces
Uyglekuty	Hand	137	Traces
Uyglekuty	Diamond	590	Traces
Katangly	Rotary	2,273	18.9
Katangly	Rotary	2,159	Traces
Katangly	Hand	195	Traces
Katangly	Hand	145	a little
Katangly	Hand	103	a little
		23,804	524.4

yielded by means of a gusher is fixed by the Soviet Government three or more times higher than that of oil pumped out may be a factor in this situation.

Japanese geologists have now proved the presence of anticlines within the oil-bearing belt, which had been already postulated by Russian geologists. The new wells drilled during the last few years are placed as close as possible to the axes of anticlines. But even

after the five years of examinations done by the best Japanese geologists and engineers, stratigraphic, and sometimes tectonic, relations of different oil regions, in a few cases even of different parts in the same oil field, are still imperfectly understood. Scarcity of natural outcrops is largely responsible for this, in addition to the rather complicated geologic structure of the eastern coast of Sakhalin Island. Comparison of different formations is done by the

TABLE III

THE NUMBER OF WELLS OF DIFFERENT DEPTH

Depth (Feet)	Number	Per Cent
0– 300	11	35.5
300– 600	6	19.4
600–1,200	9	29
1,200–1,800	0	0
Below 1,800	5	16.1
	31	100

TABLE IV

THE OUTPUT FROM DIFFERENT WELLS

	Number	Per Cent	Per Cent
Dry holes	5	16.1	16.1
Traces of oil	12	38.8	54.9
A little oil	5	16.1	
9.5–23.5 bbls. a day	6	19.3	29.0
113.5–189.0 bbls. a day	3	9.7	
	31	100.0	100.0

Japanese geologists largely on a basis of petrologic character, paleontological conditions having been studied comparatively little. The presence of a few oil-bearing horizons is established, but not their succession and correlation. It may be that the oil-bearing strata of the southern fields are older than those in the Okha region. At Okha the folding is rather slight, strata dip eastward and westward from the axis of anticline not more than 15 degrees. It is much more intensive in the southern fields, particularly in the Nutovo district, where the eastern flank of the anticline dips about 80 degrees and the western from 60 to 70 degrees.

The following analysis (I) of Sakhalin oil has been made of a

sample received from the deep horizons in the Okha field. The other (II), an old analysis, given here for comparison, represents oil from the Nutovo district collected on the surface.

ANALYSES OF SAKHALIN ISLAND OIL

	I	II
Specific gravity	0.930	0.899
Color	black	black, a little greenish
0–150 degrees	1.5	0.5 per cent
150–275 degrees	28.7 per cent	
150–300 degrees		37.0 per cent
Over 275 degrees	69.6 per cent	
Over 300 degrees		59.0 per cent

Production of the oil fields of Sakhalin Island is still very small, concentrated chiefly at the most promising place at Okha, and not developing as yet beyond the limit of an extensive prospecting. The real business still remains for the future.

The existing installation is very poor, and the work is carried on in a primitive way. Oil is pumped out into a basin, where it clears after a time from water. Water is pumped out from this basin into another one in which a little additional oil is extracted. Oil is stored in a few clay basins and tanks, the largest of them with a capacity of 5,000 tons. On February 25, 1925, there were stored on Sakhalin Island, or more particularly at Okha, 45,316 barrels of oil. The amount of oil delivered during the last few years as fuel to the Japanese destroyers is estimated at 35,628 barrels. Oil is transported from the wells at Okha to the shore by means of a pipe 2½ miles long. The yearly amount of oil produced at Okha has been reported as follows:

PRODUCTION OF OIL AT OKHA, 1923–25

Years	Total Production Barrels	Used Locally Barrels
1923	6,923	6,694
1924	83,967	15,886
1925*	45,523	8,510

*Only for the first six months of the year.

The gas, which is very abundant in some wells, is not utilized as yet and is, in fact, considered rather a nuisance.

Conditions on Sakhalin Island are quite unfavorable for oil production as the climate is very severe, with a long, cold winter and

short summer. The population on the eastern shore of the island is extremely sparse, and practically all labor must be imported. The eastern shore has a few natural harbors, but all of them are very shallow and are not available for steamers of more than 1,000 tons. Besides, these harbors are open only during four months, being covered with thick ice the rest of the year.

Owing to such conditions the expenses of prospecting amounted to about $100.00 per foot drilled. This will, of course, be much lower from now on.

It is rather difficult to foresee how the industry will be organized by Japan. The technology of the oil production would not be very different from that in Japan or in other oil-producing countries. The geological conditions of the Sakhalin localities are also similar to those known to the Japanese at home. They had a rich opportunity during their prospecting to become familiar with local conditions and have learned the choice of the best methods. For example, the diamond drilling was a complete failure, and the most efficient has been found to be the rotary system, although the cable system can also be used. The outstanding difficulties are in the physical, economic, and political conditions of Sakhalin Island. As oil produced in winter has to be stored eight months or more, an extensive storage becomes necessary. The yearly production of oil must be exported during the short navigation period, and navigation is greatly handicapped by the shallowness of the harbors of the eastern shore and by the small size of the boats that must be used.

The greatest interest of Japan in the Sakhalin oil is to get fuel for her navy, especially in case of war, when that country would be confined to her own resources of oil which are entirely insufficient, as about three quarters of the oil now used in Japan is imported. Storage on the eastern shore of Sakhalin, the most natural location for it, would be absolutely unprotected during war, as harbors here may not be fortified. Moreover, the eastern coast of the island could be easily blockaded by the navy of an enemy. The idea is growing in some circles to make all storage on the western shore of Sakhalin, constructing pipe lines to bring the oil across the island. In this case Japan would have the oil on the sea which she would be more likely to control even in war conditions. For Japan, the Sakhalin oil business is of greater import than for any other country.

GEOLOGICAL NOTES

TWO NEW SALT DOMES IN TEXAS

There is "something new under the sun." For the first time in the history of the Gulf Coast oil industry it is possible to announce, with absolutely no risk that any informed student of the salt-dome area will question the accuracy of the announcement, that a new salt dome has actually been discovered, without any well having been drilled to prove the discovery or even to test the area. This is tantamount to the assertion that our confidence in the seismograph (by means of which this discovery was made) in geophysical exploration has already come to be perfect. In other words, wherever the seismograph registers the presence of a buried salt dome Gulf Coast operators generally are now willing to accept the verdict just as confidently as though a well had actually been drilled into the dome material.

In the present instance the favorable area has been entirely leased and royalties have been bought and sold on a price basis nearly, or quite, equal to that which would have prevailed had a well actually been completed in salt or cap rock.

The new dome, which will probably be called the Moss Bluff dome, is in southern Liberty County, near the Chambers County line, just east of Trinity River. There is a slight, but conspicuous, surface elevation over the buried dome which has caused the area to be regarded with suspicion for years. The surface evidence is so slight, however, that no one has ever been persuaded to drill upon it, even though just to the north the Turtle Bayou Oil Company three years ago drilled several wells, in which oil showings were reported.

The discovery was made about June 1 by the Gulf Production Company, using a seismograph leased from the Rycade Oil Corporation and operated by members of that organization. Within a few days, and before full advantage could be taken of the discovery (so keen is competition today on the Gulf Coast), other companies had "shot" the area and confirmed the results. Consequently, the acreage is divided between several of the Gulf Coast operators, with the Gulf Company probably in best position.

The Moss Bluff dome is covered at the surface by Beaumont clay. The depth to the top of the cap rock is estimated from 500 to 1,000 feet.

The dome is slightly larger, perhaps, than the average dome, and probably has an east-west diameter somewhat longer than its north-south diameter.

Credit for the discovery of the other hitherto unknown salt dome, which belongs to the interior group of Texas domes, goes largely to an amateur geologist, M. A. Davey, of Palestine, Texas. The original discovery by Mr. Davey was made several years ago, although the dome was actually proved only within the last two weeks, when the Humble–Rio Bravo joint test in the suspected area finally drilled into salt at a depth of 2,550 feet. Mr. Davey is an old resident of Palestine, who has spent his spare time for years in an individual study and interpretation of the local geology. His findings in the vicinity of the new salt dome were submitted to several geologists, including Paul Applin, Wayne Bowman, and Lyman Reed, of the Rio Bravo Oil Company, and Moses Knebel and H. J. McLellan, of the Humble Oil & Refining Company. These men recognized the importance and significance of the surface evidence of uplift, and share with Mr. Davey the credit for the discovery. The uplift was proved by shallow drilling, and the identification of the uplifted beds was made by Mrs. Esther Richards Applin, of the Rio Bravo Oil Company, and Miss Alva Ellisor, of the Humble Oil & Refining Company, in their respective laboratories.

This dome, which may be called the Boggy Creek dome, is situated on the Anderson-Cherokee county line. At the surface it is evidenced by a "window" of Wilcox outcrops surrounded by Claiborne beds. There are also sharply dipping beds aligned as though by faulting, saline flats and springs, and small mud volcanoes, or craters.

Drilling has shown that the top of the Midway has been uplifted some 1,500 feet on top of this dome. The Cretaceous section is partly missing or shortened on top of the dome, which appears to be entirely sheathed by a thick anhydrite cap rock, like many of the domes nearer the coast. Beds of Buda age (uppermost Comanchean) have been identified in the well samples just above the cap rock, and appear to be the lowest beds stratigraphically which are intact over the top of the dome. This, according to Sidney Powers, is likewise true of the other interior domes of Texas.

Several shows of oil and gas have been encountered in the drilling so far completed at Boggy Creek. All of the acreage in the critical area is held by the Rio Bravo Oil Company and the Humble Oil & Refining Company, largely in joint interest.

WALLACE E. PRATT

HOUSTON, TEXAS
July, 1926

SHORT CUTS IN PICKING OUT AND SECTIONING FORAMINIFERA

When specimens of foraminifers are not especially plentiful in samples taken from well cuttings or from outcrops, we have found in many instances that it is very advantageous to employ heavy liquids to concentrate or separate them.

The principle involved is the same as that commonly used in separating minerals of different specific gravities. The methods generally employed in the latter case are set forth in articles and textbooks on petrography and petrographic methods.[1]

The only time when heavy solutions cannot be used advantageously in separating foraminifers and other small organisms from a soft matrix in which they occur, is when they have the same specific gravity as the matrix. Generally, however, there is at least a small difference in specific gravity between the two.

The heavy liquids which we have found most convenient to use are either bromoform or Thoulet's solution (potassium mercuric iodide) as these are easily concentrated or diluted to just float or sink the foraminifers according to whether they are heavier or lighter than the matrix in which they are found. The separation is usually carried out in an ordinary separatory funnel like those commonly used in separating heavy minerals. Washed samples are usually preferable.

Using this method, we frequently have been able to separate great numbers of Foraminifera in a few minutes. In some samples in which specimens were scarce, we have been able by this method to secure more in fifteen minutes than could be picked out by hand in two or three days. One great advantage is that a greater number of individuals allows a selection of better preserved specimens for identification.

Another short cut which we find very helpful in removing specimens of the so-called large Foraminifera from a limestone matrix in which they are embedded, is to remove them by means of a small oxy-acetylene torch, using a modification of the method recently described by G. Dallas Hanna.[2] If the limestone is not too sandy, large foraminifers such as the larger orbitoids may be removed very satisfactorily by using a No. 00 tip on the torch. The advantage in removing the specimens from the matrix is very obvious because it allows a study of the external ornamentation and a definite orientation in making thin sections. Another great saving is in

[1] A very good recent publication is *Petrographic Methods and Calculations* by Arthur Holmes, 1921, published by Thomas Murby Co., London.

[2] *Journal of Geology*, Vol. 32 (1925), pp. 545–47.

the number of thin sections needed for a specific determination. In accidental sections made from slices of rock containing several species of large Foraminifera it is often very difficult to be sure whether a given vertical section should be ascribed to the same species as other specimens in the same slice which are cut in different directions. When the foraminifer is removed, its definite characters can be determined at once without making a large number of thin sections

In making horizontal sections of orbitoids, one is frequently confronted with the difficulty that the equatorial layer is not in one plane. This can sometimes be overcome in the following way: after the specimen has been ground down to the equatorial cells in one spot, dry the specimen, and with a fine camel's hair brush scarcely moistened with acid, eat away the unnecessary cells above the median layer. By this trick, one can frequently expose the whole surface he desires or at least more of it than would be possible by grinding alone. The strength and quantity of acid on the brush can be varied to meet the needs of each specimen, but usually a very small amount of concentrated acid can be more easily controlled and gives more satisfactory results. After the foraminifer has been ground and eaten on one side, it can be mounted and subjected to the same treatment on the other. This method of supplementing grinding by corroding with acid allows a larger area of the equatorial layer to be exposed at one time for study.

FLOYD AND HELEN HODSON

PALEONTOLOGICAL LABORATORY
CORNELL UNIVERSITY, ITHACA, N.Y.
August 10, 1926

DISCUSSION

ORIGINAL SOURCE OF OIL IN COLOMBIA

In the April number of the *Bulletin* I read a very interesting article written by Mr. F. M. Anderson, on "Original Source of Oil in Colombia."

The article presents new and interesting details principally from the coast region. It is to be wished that oil geologists who travel in and study Colombia would co-operate and publish more on the subject. Although I do not share all views of the writer, I refrain from criticizing the article, which undoubtedly enlarges very much our knowledge of the geology of this country.

Anderson differs from the opinion that I suggested three years ago, that oil in Colombia has its probable origin in the Villeta series of the Cretaceous. Generally speaking, the source of oil in most countries is somewhat unknown and problematic, and this also applies to Colombia.

The probable source of oil, to my mind, is not only the Villeta but the Guadelupe series of the Cretaceous. The black foraminiferal Guadelupe series and also the Villeta limestone, for example, in the upper Carare–Rio Minero and other localities are in places exceedingly rich in bitumen; when broken with the hammer, these rocks have a strong odor of petroleum. The Barzelosa group and the Honda schists of the Tertiary in the Magdalena Valley do not show a content of bituminous substances. This also applies to the Guaduas group of the Eocene, interbedded between these and the Cretaceous beds, excluding of course the coal seams of the Guaduas formation.

In the only productive oil fields of Colombia, at Barranca Bermeja, the Barzelosa and Honda groups have a thickness ranging from 3,000 to 4,000 meters, demonstrating that the Cretaceous series occurs at a very great depth. I assume the bitumen was distilled at depth, and the upper series penetrated later. The center and the upper parts of the Honda formation, being of an andesitic tuff-sandstone character, seem to be fitted ideally for oil accumulation. At the coast where the marine Tertiary groups are rich in organic materials, the general conditions may be different.

The following example may serve for the origin of oil in Cretaceous beds. In the Magdalena Valley and in the eastern Cordillera we find seeps in the Cretaceous beds. At Simití in the Magdalena Valley asphalt fills fissures in the Villeta limestone (Cretaceous). At Guataquí in the Magdalena Valley oil emanates from the Guadelupe series (Cretaceous), where two dry boreholes were put down by the Transcontinental Oil Company. In the upper regions of the eastern Cordillera asphalt has been reported from the Guaduas and Guadelupe series. This is to show that we encounter asphalt and oil seeps from the Villeta up to the Honda beds. On the other hand we do not find oil or asphalt in regions which

lack the Cretaceous formations underground; for example, in the most extensive parts of the central and western Cordilleras, and also in the Cauca and Patia valleys, situated between these Cordilleras, the beds of which contain many geological aspects of those in the Magdalena Valley. Therefore, I am of the opinion that oil in Colombia emanates from the Cretaceous beds, particularly in the only productive zone in the Magdalena Valley.

OTTO STUTZER

BOGOTÁ, COLOMBIA
July, 1926

UNUSUAL NATURAL GASES

In the April issue of the *Bulletin*, under title of "New Zealand Oil Discovery," Mr. Frederick G. Clapp expresses a desire for information concerning the occurrence of heavy production of high percentages of carbon dioxide in oil fields having associated igneous rocks.

Although not so stated by Mr. Clapp it is inferred that he believes there is a causal relationship existing between the andesite porphyry and the high percentage of carbon dioxide.

Two rather exceptional gas analyses have come to the attention of the writer, the details of which are here given.

The Floersheim State well (elevation 5,875 ft.), drilled by the California Company, Sec. 15, T. 23 N., R. 24 E., in Colfax County, New Mexico, penetrated a sand at 1,509–1,510 feet that yielded a flow of one-fourth million cubic feet of gas of the following composition: Carbon dioxide, 67 per cent; oxygen, 4.10 per cent; nitrogen, 28.70 per cent; methane, 0 per cent; ethane, 0 per cent. The gas contains unusually high percentages of carbon dioxide and oxygen. The drill is reported to have entered granite (granite wash) at 1,979 feet and to have continued in the same formation to 2,556 feet, where the hole was abandoned.

On Wagon Mound the Arkansas Fuel Oil Company drilled the C. F. Kruse No. 1 well in Sec. 11, T. 19 N., R. 21 E., in Mora County, New Mexico. Gas was encountered at 1,140–1,163 feet and another heavy flow of five million cubic feet at 1,420–1,425 feet. Drilling was continued to a depth of 2,613 feet, with the last 400 feet in granite wash. On analysis the gas gave the following percentages: Carbon dioxide, 90 per cent; oxygen, 2.2 per cent; methane, 0 per cent; ethane, 0 per cent; nitrogen, 7.8 per cent. An exceptionally high percentage of carbon dioxide is to be noted.

The results of igneous activity in northeastern New Mexico are not an uncommon sight. Heavy flows of Quaternary lavas cover much of the Cretaceous rocks exposed in that area, which must have subterranean connection with the original sources. It is not impossible to suppose that the intruding members reacting upon the limestones may have evolved large volumes of carbon dioxide, which accumulated in the more porous sandstone beds. The stratigraphic posi-

tions of the gas-producing sands in the two wells are undoubtedly very closely related. No petroleum production has been reported from this area. Although the known geological relationships offer a plausible explanation of the presence of high percentage carbon dioxide gas as a result of possible reaction of igneous activity upon the sediments, there is, however, no definite evidence that the two factors are directly connected, and the assumption must stand the test of further investigation.

WALTER B. LANG

U. S. GEOLOGICAL SURVEY
August 25, 1926

OIL POSSIBILITIES OF THE BLACK HILLS REGION

Although I would hardly contend that many Salt Creeks lie undiscovered near the Black Hills, my several years of work there lead me to disagree with Mr. Sinclair's conclusion that "all monoclines, all truncated anticlines, all terraces that have any chance of being productive, have been drilled in the Black Hills region."[1] Aside from a few minor points not worth an issue, his other statements appear valid in the light of development since 1922. Pending the publication of my final report on the area by the U. S. Geological Survey, I can only reaffirm my belief that some folds, such as those mentioned in several press-notices,[2] are worthy of a test, at least when oil goes up.

"Rocky Point Plunging Anticline, Wyoming," *Press Notice 17,915*, Nov. 14, 1924.

"Possibility of Finding Oil in Anticline near Edgemont, South Dakota," *Press Notice 8,580*, Aug. 19, 1926.

W. W. RUBEY

WASHINGTON, D.C.
September 9, 1926

ERRATUM

Attention is directed to a correction to be made in the August *Bulletin*, Volume 10, No. 8, p. 809, in relation to the discussion following the paper on the "Oil Possibilities of the Black Hills Region," by Mr. E. G. Sinclair. The first line of the discussion is correct:

"Walter Stalder: Is the Osage field drilled on a closed fold?"

The second line should read:

"Mr. Sinclair: No."

The second paragraph on the page, which is attributed to Mr. Sinclair, is Mr. Stalder's expression. Mr. Sinclair's remarks commence at the beginning of the third paragraph from the end: "In answering the remarks of Mr. Stalder. . . . ."

[1] E. G. Sinclair, "Oil Possibilities of the Black Hills Region," this *Bulletin*, Vol. 10 (1926), pp. 800–809.

[2] "Possibility of Finding Oil in Deep Sands near the Osage Field, Wyoming," *U. S. Geol. Survey Press Notice 15,869*, Aug. 27, 1923.

THE ASSOCIATION ROUND TABLE

THE DENVER MEETING

In a natural environment of inspiring physiography and with an historical background of pioneer daring and trail-blazing, the Denver meeting was a fitting occasion for something new and experimental in American Association program methods. The increasingly lengthy and congested programs of recent years have far outgrown the time available at a convention for anything like satisfactory presentation and discussion of all the different problems in which the members are interested. In order to avoid the difficulties of an overcrowded program, President Alex McCoy planned early in the year to have the coming meetings consider one definite theme for study and discussion. When the mining societies of the Rocky Mountain area extended the invitation to join them in the Western States Joint Convention, they afforded the opportunity to give the plan a fair trial. Judged by the number of the editor's discussion blanks that were used to record the many remarks brought out by the few select papers on the theme of Rocky Mountain geology correlated with that of the panhandles on the east and the Pacific coast on the west, and by the favorable comments heard from the groups in Program Chairman Dean Winchester's display room, this trial of the bulletin-board method of presentation was a success.

Only eight papers were orally presented. Both author and audience had ample time for expression. No gavels were broken warning speakers of time limits. Many papers not listed on the program were exhibited with accompanying maps, models, specimens, and other illustrations on map boards and tables in the bulletin room. Members exercised their own choice of subject and time for study or discussion.

The registration desks of each of the four participating organizations—the American Association of Petroleum Geologists, the Western Division of the American Mining Congress, the Colorado Chapter of the American Institute of Mining and Metallurgical Engineers, and the American Silver Producers' Association—opened for business Monday morning, September 20, in the lobby of the Cosmopolitan Hotel, which was a commodious and hospitable convention headquarters. Miss Enith Larson, of the Midwest Refining Company office, and her assistants very pleasingly registered one hundred petroleum geologists and seventy-five guests.

The general convention opened Monday afternoon, but the association sessions did not commence until Tuesday afternoon, September 21. President McCoy opened the meeting with an outline of the association's aims and plans

for the year, and introduced J. P. D. Hull, the newly-appointed acting secretary-editor, who briefly outlined activities at headquarters recently established in Tulsa. Charles M. Rath, general chairman of the local committee, announced the program for the week and welcomed the association to Denver. The following papers were presented at the two sessions on Tuesday and Thursday:

PROGRAM

Tuesday Afternoon, September 21

1. Geology of Western Kansas.....GLENN C. CLARK
2. The Amarillo District.....J. V. HOWELL
3. Permian of Oklahoma and the Panhandle of Texas (a paper to be published by the Oklahoma Geological Survey).....CHARLES N. GOULD

Thursday Forenoon, September 23

4. Upper Paleozoic Geology of Southwest Texas (read by W. A. J. M. van Waterschoot van der Gracht).....J. W. BEEDE
5. Rocky Mountain Geology.....T. S. HARRISON AND R. C. COFFIN

Thursday Afternoon

6. Salt Domes of Permian and Pennsylvanian Age in Southeastern Utah and Their Influence on Oil Accumulation
H. W. C. PROMMEL AND H. E. CRUM
7. Folding or Shearing: Which? (read by Robin Willis).....BAILEY WILLIS
8. The Northern Cordilleran Geosyncline and Its Relation to Petroleum Accumulations.....C. A. FISHER AND E. RUSSELL LLOYD

At the sessions of the Institute and the Mining Congress interesting papers were presented but were not heard by all of the geologists because of their own meetings. George Otis Smith presented "The Ever New West," and Max W. Ball gave a paper on "Value of United States Scientific Research."

All organizations joined in a smoker for the men and a reception for the ladies on the mezzanine of the Cosmopolitan Hotel Monday night, after which all gathered in the Colorado ballroom for dancing. The minstrel entertainers at the smoker, through their enticing variations of "Turkey in the Straw," drew out unexpected and spontaneous talent from the pioneers of the mining members.

Charming entertainment Wednesday afternoon in the form of a bridge tea at Cherry Hills Country Club under the auspices of the Women's Auxiliary of the A.I.M.E. was appreciated by the visiting ladies, and on Thursday the Denver petroleum geologists' ladies gave a delightful luncheon for visiting and resident ladies at the home of Mrs. Thomas S. Harrison.

Wonderful automobile trips were provided members and guests to the Colorado School of Mines and to Indian Hills, where the Mining Bureau of the

Denver Chamber of Commerce and the Colorado Mining Association furnished the crowd unique entertainment with an elk barbecue and a realistic Pueblo war dance in the nearby Indian village. The party remained to dance at the Indian Hills clubhouse till the stars grew pale. The moonlight drive from Lookout Mountain with the twinkling lights of Denver afar down on the plains! Members from places less blessed with scenery envied the ease with which E. Russell Lloyd's committee had only to look to Nature's lavish hand for entertainment. On the Fort Collins–Wellington trip, the Union Oil Company of California was the generous host at a splendid dinner, after which James M. Douglas admirably supervised the inspection of the oil fields.

The Resolutions Committee presented the following:

Be it resolved, That we, the members of the American Association of Petroleum Geologists in meeting assembled at Denver on September 23, 1926, hereby express our deep appreciation and hearty thanks to all those who have made this meeting so profitable and enjoyable to the members and their wives in attendance, and specifically to the following: The Local Committee on Arrangements; Rocky Mountain Association of Petroleum Geologists; American Institute of Mining and Metallurgical Engineers (Colorado Chapter); American Mining Congress (Western Division); Women's Committee of the Rocky Mountain Association of Petroleum Geologists; Women's Auxiliary, American Institute of Mining and Metallurgical Engineers (Colorado Chapter); Mr. Charles M. Rath, president of Rocky Mountain Association of Petroleum Geologists and chairman of the local committee; Mrs. T. S. Harrison, chairman of the local women's committee; Miss Enith Larson, in charge of registration; Mining Bureau of the Denver Chamber of Commerce; Cosmopolitan Hotel; Cherry Hill Country Club; Union Oil Company of California; Marland Oil Company of Colorado; The Texas Company; Continental Oil Company; Producers and Refiners Corporation; and The Midwest Refining Company.

And be it further resolved, That copies of these resolutions be submitted to the American Association of Petroleum Geologists for publication in the Round Table of the Association *Bulletin*, and be sent to those specifically mentioned.

(*Signed*) MAX W. BALL
JOHN L. RICH
J. P. D. HULL, *Committee*

Those who were privileged to take advantage of Frank A. Wadleigh's "one way" round-trip reduced rate on the D. & R.G.W. through the Royal Gorge to the oil shale deposits near De Beque enjoyed in truth a rare opportunity. Dean Winchester and other shale enthusiasts (affectionately classed as "shale nuts") were in their glory as hosts, guides, chauffeurs, companions, entertainers, even bankers. The Mahogany shale ledge—described as good for billiard balls, table tops, or 100 gallons to the ton—held the novitiates of the party spellbound until they returned to the fried chicken handout at the home of Joseph Bellis of Grand Valley. Afterward some of the high spots were the Bureau of Mines

shale plant near Rulison, the natural hot baths, and the supper furnished by the local committee at Glenwood Springs, and then again the Royal Gorge and Denver.

J. P. D. HULL

MEMBERS REGISTERED AT THE CONVENTION

Anderson, Amil A., Wichita, Kan.
Aurand, Harry A., Denver, Colo.
Aurin, F. L., Ponca City, Okla.
Bain, H. Foster, New York City
Baldwin, Harry L., Jr., Denver, Colo.
Ball, Max W., Denver, Colo.
Bartram, John G., Casper, Wyo.
Bauer, C. Max, Amarillo, Tex.
Blanchard, W. Grant, Jr., Denver, Colo.
Boyle, A. C., Jr., Laramie, Wyo.
Brainerd, A. E., Denver, Colo.
Brown, J. Earle, Fort Worth, Tex.
Butcher, Cary P., San Angelo, Tex.
Carsey, J. Ben, San Angelo, Tex.
Clark, Glenn, Ponca City, Okla.
Clifton, R. L., Enid, Okla.
Dannettell, M. Q., Barr Lake, Colo.
Davies, F. A., Billings, Mont.
De Ford, Ronald K., Denver, Colo.
Denison, A. R., Enid, Okla.
Douglas, James M., Fort Collins, Colo.
Emery, W. B., Boulder, Colo.
Fath, A. E., Chrisman, Ill.
Fees, L. V., Denver, Colo.
Finch, John W., Denver, Colo.
Fisher, C. A., Denver, Colo.
Gester, S. H., San Francisco, Calif.
Gish, Wesley G., Tulsa, Okla.
Gouin, Frank, Duncan, Okla.
Gould, Charles N., Norman, Okla.
Grinsfelder, Sam, Fort Collins, Colo.
Griswold, C. T., Raton, N.M.
Gulley, M. G., Ponca City, Okla.
Hall, Roy H., Wichita, Kan.
Heaton, R. L., Denver, Colo.
Henderson, Junius, Boulder, Colo.
Hendrickson, Victor J., Denver, Colo.
Higgins, D. F., Loveland, Colo.
Hill, Benjamin F., Cripple Creek, Colo.
Hintze, F. F., Denver, Colo.
Holloman, Roy, Denver, Colo.
Hull, J. P. D., Tulsa, Okla.
Howell, J. V., Amarillo, Tex.
Howell, W. F., Shelby, Mont.
Hughes, C. Don, Amarillo, Tex.
Hunt, Edwin H., Denver, Colo.
Hupp, J. E., Casper, Wyo.
Iddings, Arthur, Toronto, Canada
Irwin, Joseph S., Denver, Colo.
Johnson, J. Harlan, Golden, Colo.
Kennedy, Luther E., Tulsa, Okla.
Knapp, Arthur, Philadelphia, Pa.
Knox, J. K., Bartlesville, Okla.
Lavington, Charles S., Denver, Colo.
Lloyd, E. Russell, Denver, Colo.
Loomis, Harve, Longmont, Colo.
Lounsbery, D. E., Abilene, Tex.
Lupton, Charles T., Denver, Colo.
McCoy, Alex W., Denver, Colo.
McCune, Paul, Cincinnati, Ohio
McGill, William M., Denver, Colo.
McKim, J. W., Denver, Colo.
Miller, E. F., Denver, Colo.
Morley, Harold T., Denver, Colo.
Nelson, W. S., Denver, Colo.
Newman, T. F., Abilene, Tex.
Norton, George H., Wichita, Kan.
Packard, H. J., Denver, Colo.
Patton, H. B., Denver, Colo.
Peterson, C. J., Denver, Colo.
Philbrick, E. P., Denver, Colo.
Prommel, H. W. C., Wichita Falls, Tex.

Prout, F. S., Roswell, N.M.
Rae, Colin C., Denver, Colo.
Rath, Charles M., Denver, Colo.
Renick, B. Coleman, Washington, D.C.
Rennie, W. E., Denver, Colo.
Rhoades, R. S., Denver, Colo.
Rich, John L., Ottawa, Kan.
Riggs, R. J., Bartlesville, Okla.
Roberts, M. E., Amarillo, Tex.
Ruby, Glen M., Denver, Colo.
Scudder, E. W., Denver, Colo.
Sealey, F. C., Wichita Falls, Tex.
Selig, A. L., Shreveport, La.
Shaw, Everett S., Denver, Colo.
Smith, George Otis, Washington, D.C.
Stewart, Hugh A., Denver, Colo.
Toepelman, W. C., Boulder, Colo.
Tomlinson, C. W., Ardmore, Okla.
Van der Gracht, W. A. J. M., Ponca City, Okla.
Vernon, Jess, Okmulgee, Okla.
Vorbe, Georges, Thurber, Tex.
Walker, W. L., Bartlesville, Okla.
Warner, Julius H., Denver, Colo.
Weinzierl, John F., Houston, Tex.
Westby, G. H., Denver, Colo.
Whitney, P. B., Denver, Colo.
Winchester, Dean E., Denver, Colo.
Younkman, Harry, Tulsa, Okla.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

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William David Gray, Tulsa, Okla.
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Jasper W. Paulsen, Jr., Los Angeles, Calif.
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Quentin D. Singewald, Tampico, Mexico
J. P. D. Hull, George E. Dorsey, Lewis B. Kellum
Merwin H. Soyster, Los Angeles, Calif.
E. Huguenin, William S. W. Kew, R. E. Collom
Elisabeth Stiles, Houston, Tex.
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Marshall A. Harrell, San Angelo, Tex.
Frederic H. Lahee, R. E. Rettger, Clifton M. Keeler
Ivy M. Hawkins, Shreveport, La.
Henry V. Howe, J. P. D. Hull, L. S. Harlowe
Helen K. Hodson, Ithaca, N.Y.
Floyd Hodson, C. M. Nevin, Dabney E. Petty
Paul L. Keller, Amarillo, Tex.
C. Max Bauer, Wm. L. Clark, D. E. Lounsbery
Hugh W. McClellan, Bartlesville, Okla.
Joseph A. Cushman, W. D. Kleinpell, Donald D. Hughes

FOR TRANSFER TO FULL MEMBERSHIP

Thomas L. Coleman, Okmulgee, Okla.
C. L. Severy, W. R. Hamilton, Hale B. Soyster

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

EDWARD D. NOLAN, chief geologist of the General Petroleum Corporation, Los Angeles, died in San Francisco, September 5, at the age of thirty-six years, following a brief illness.

BYERS EMRICK is working at Conrad, Montana, as chief assistant in the Rocky Mountain district to RALPH ARNOLD, Los Angeles, California.

MARION H. FUNK, geologist with the Louisiana Oil Refining Corporation of Shreveport, was transferred to Cisco, Texas, last summer in the interests of his company.

A. L. SELIG, chief geologist for the Southern Crude Oil Purchasing Company of Shreveport, Louisiana, spent his vacation in the West last September. Mr. and Mrs. Selig attended the Rocky Mountain Convention of the Association at Denver.

L. S. HARLOWE, chief geologist for the Louisiana Oil Refining Corporation of Shreveport, spent part of September in Kentucky, inspecting company property.

CHARLES R. FETTKE and W. A. COPELAND, of the Carnegie Institute of Technology, who have been making a detailed geological survey of the Bradford Quadrangle for the Pennsylvania Topographic and Geologic Survey, have returned to Pittsburgh. Field work will be continued next summer. That part of the quadrangle included within the limits of the Bradford oil field is being mapped on a scale of 500 feet to the inch with structure contours on top of the Bradford sand at 5-foot intervals. The different methods of oil recovery at present employed and the results obtained are also being studied.

JOHN R. SUMAN, vice-president and general manager of Rio Bravo Oil Company, Houston, spent his vacation in September traveling through west Texas.

SHERIDAN A. THOMPSON, geologist for Vacuum Oil Company at Houston, and Miss Mary Florine Ashcroft of Sulphur Springs, Texas, were married early in September at the bride's home in north Texas. Mr. and Mrs. Thompson spent their honeymoon at Port Byron, New York.

L. H. FREEDMAN, geologist and land man for the Marland Oil Company of Texas at Houston, for the past year, resigned September 15, to go with the Goodman Drilling Company in charge of the geological and land departments. Headquarters will be maintained in Dallas.

PAUL J. MCINTYRE, manager of the land department of the Phillips Petroleum Company with headquarters at Bartlesville, Oklahoma, was in Texas last September watching his company's first wildcat oil producer in that state. The well is located in the southwest corner of Jones County.

A. M. MEYER, formerly with the Texas Company at Ardmore, has joined the staff of the Atlantic Oil Producing Company to take charge of their work in southern Oklahoma.

WILLIS T. LEE, of the U. S. Geological Survey, died June 16.

CLARENCE M. SALE, formerly of the New England Oil and Pipe Line Company, is in charge of the Holdenville district for the Atlantic Oil Producing Company.

A. I. LEVORSEN, formerly district geologist in Okmulgee for the Gypsy Oil Company, is now chief geologist for the Philmack Oil Company with offices in the Atlas Life Building, Tulsa.

GEORGE EDWIN DORSEY, consulting geologist, Box 411, Tulsa, Oklahoma, spent part of October and November in Baltimore, Maryland.

W. ARMSTRONG PRICE has moved his office to 912 Bankers Mortgage Building, Houston, Texas.

CARL D. SMITH, consulting geologist of Tulsa, has moved to Agra, Oklahoma.

D. V. CALLAHAN, formerly with the Atlantic Oil Producing Company, is now geologist for Westheimer and Daube, at Ardmore, Oklahoma.

DONALD C. BARTON has joined the staff of the Geophysical Research Corporation at Houston and will also act as consulting geologist for the Rycade Oil Corporation.

E. CALL BROWN has resigned as chief geologist of the California Petroleum Corporation of Los Angeles to engage in consulting work with an office in that city.

WILLIAM J. MILLARD, of Philadelphia, is consulting geologist for the Trinidad Oilfields, Ltd., and can be reached at Brighton, Trinidad, B.W.I.

DOUGLAS R. SEMMES, consulting geologist with headquarters care O. B. HOPKINS, 25 Broadway, New York City, has returned from Venezuela and is working in Texas.

ED GEORGE, connected for many years with the geological and land departments of the Amerada Petroleum Corporation, has joined the geological staff of the Independent Oil and Gas Company to work out of Okmulgee, Oklahoma.

JESS VERNON, district geologist of the Amerada Petroleum Corporation, has moved from Okmulgee to Shawnee, where he is assisted by C. W. BYRON and H. M. GARRETT.

CHARLES T. KIRK, consulting geologist at Tulsa, made a professional trip to Georgia in September.

GRADY TRIPLETT is directing diamond drill work in Nova Scotia.

DANA MILLER returned from New Zealand to Tulsa last September.

A. E. FATH returned from Poland in September and resigned from the Vacuum Oil Company.

J. A. BOWNOCKER, state geologist of Ohio, visited the shale plants in the West during the past summer in order to determine the possibility of mining oil shale in Ohio.

THERON WASSON, chief geologist of the Pure Oil Company, has moved from Columbus, Ohio, to Chicago.

C. W. STUDT is chief geologist of the Union Gas Corporation, 120 Broadway, New York City.

MAX A. PISHEL, of Tulsa, is associated with H. C. TYRRELL in the Mid-Continent Building.

CARL B. ANDERSON, consulting geologist of Tulsa, spent his vacation in northwestern Iowa.

H. T. BECKWITH, formerly with the Indian Territory Illuminating Oil Company of Bartlesville, is now chief geologist of the Noble Oil and Gas Company of Tulsa.

R. J. METCALF, formerly with the Indian Territory Illuminating Oil Company, is now district geologist for the Transcontinental Oil Company at Fort Worth.

LEROY T. PATTON, head of the department of geology at Texas Technological College, Lubbock, Texas, announces that R. D. RUSSELL has joined the department as associate professor in charge of paleontology.

GILBERT P. MOORE, of the Standard Oil Company of New Jersey, returned in August from Argentina for a visit to the United States.

L. C. SNIDER, geologist for Henry L. Doherty and Company, of New York, spent the summer in Western Canada in professional work.

E. G. WOODRUFF, consulting geologist at Tulsa, made a business trip to Canada in July.

J. H. CLOPTON has resigned from the Aguila (Mexican Eagle Oil Company) of Mexico and returned to the United States.

Among the geologists who attended the Institute of Politics at Williamstown, Massachusetts, were C. K. LEITH, H. F. BAIN, G. H. ASHLEY, W. B. HEROY, CHARLES CAMSELL, E. DEGOLYER, F. JULIUS FOHS, A. C. LANE, G. R. MANSFIELD, and H. F. CLELAND.

CHESTER REAMS THOMAS, formerly geologist for the Amerada Petroleum Corporation, has opened an office as consulting geologist at 314 Clinton Building, Tulsa.

J. E. BRANTLY, in charge of foreign geological work for the Atlantic Refining Company of Philadelphia, is spending a few months in South America.

CHARLES O. DOUB, of Graham, Texas, worked out the geology of the area in which was drilled the discovery well of the new Cross Cut pay sand of Brown County, Texas.

J. O. LEWIS, of Tulsa, published a paper on petroleum reserves in *The Compressed Air Magazine* for June.

W. C. MENDENHALL, chief geologist of the U. S. Geological Survey, spent September on an inspection trip in the West.

A. C. VEATCH, of the Sinclair Exploration Company, New York City, returned in August from a trip to Africa.

Memorial

James V. Howe

James V. Howe died in San Antonio May 16, 1926, following an operation for appendicitis.

He was born August 14, 1880, in Rowlesburg, West Virginia. He completed the course in civil engineering in the University of West Virginia in 1904, graduating with the degree of B.S.C.E.

For several years thereafter he was engaged in railroad and other classes of engineering which took him over the greater part of the United States and included one year in Mexico. He also spent one year as instructor in the Missouri School of Mines at Rolla, Missouri.

In 1913 he located at Tulsa and specialized in geological engineering. During the past five years he was with the Tidal Oil Company, going to San Antonio in 1925 because his health necessitated his being engaged in comparatively light work. The writer knew him more than twenty years and held him in very high regard because of his keenness of mind, his integrity, and broad experience.

He is survived by his widow, his mother, a brother, and a sister.

J. H. Jenkins

Bryan Hendon

Bryan Hendon was born January 27, 1896, at Earlsboro, Oklahoma. He was one of twelve children of R. R. Hendon, Sr., who was a pioneer settler of Oklahoma. Bryan was reared as a farmer lad. He commenced his education in the rural schools of Oklahoma, and was self-supporting in all his school work, including universities. In 1919 he graduated from Oklahoma University with the degree of A.B. He obtained a Master's degree from Cornell University. At Oregon University he held a scholarship, and at the University of California he was assistant instructor in geology.

During the world-war he entered the U.S. Navy as a volunteer, and was detailed for service in engineering in the U.S. Ford Eagle Plant at Detroit. After the war he returned to civil life and after taking the A.B. degree at Oklahoma University, entered the employ of the Dutch Shell Company and sailed for Venezuela. He returned to the United States in about a year, and was employed by the Carter Oil Company at Tulsa, Oklahoma. He made geological surveys for the Standard Oil Company of New Jersey in thirteen European and African countries and states, including Spain, Italy, Jugo Slavia, and Morocco. While stationed at Casablanca, Morocco, he was engaged in detailed work and entered Africa a distance of 1,100 miles. He returned on leave from Africa and entered Cornell University. He again went to Morocco for the Standard and was captured by the Arabs, charged with being an English spy. He was tried at the court of an Arab chief, but proved himself to be innocent by displaying the American marks on his instruments.

Following exoneration, he was invited to dine with the chief of the tribe, and he was given a military escort and pass throughout the kingdom.

Bryan again returned to America and re-entered Cornell, where he took a Master's degree. From Cornell he went to Oregon University, and thence to Berkeley. He sailed for Venezuela in February, 1925, for the Standard Oil Company of California. He died August 18, 1926.

Claude Hendon

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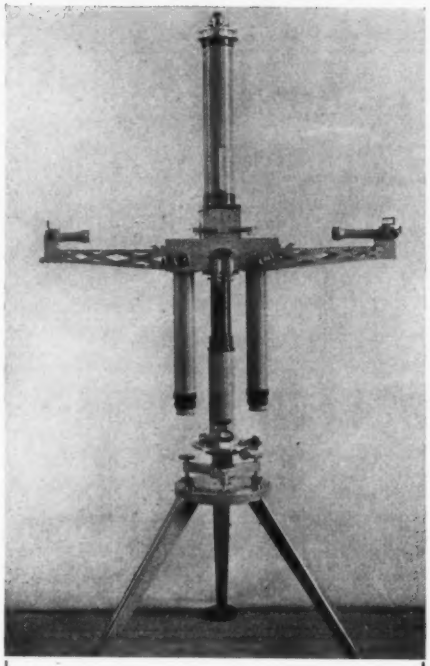

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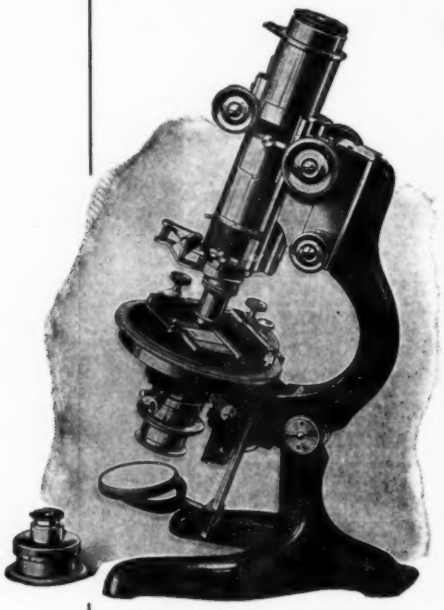

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